SmartRadar Flexline

Honeywell Enraf

Service manual professional

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GENERAL

The SmartRadar FlexLine implements, amongst others, the function product level. Because of complexity functionality is accommodated by several tab sheets in Engauge. Next to the standard available tab sheet ‘Product level’ the following tab sheets also belong to the function product level: ‘Compensations’, ‘Obstructions and zones’, ‘Antenna Exchange’, ‘Peak Selection’, ‘Heimdall’, ‘Advanced’ and ‘Miscellaneous’

COMMISSIONING

Level start-up (Tab sheet: Product level)

Similar to basic. In addition:

Installation on oversized (double sized) stilling well

The SmartRadar FlexLine is configured for the antenna in the factory and the settings for the antenna generally don't have to be adjusted. There's one exception however: if an S-antenna is positioned in a stilling well and the stilling well diameter is twice the antenna size (e.g. a S06 antenna in a 12" stilling well) the [Antenna mode] should be changed from TE01 to TE02 (Tab sheet 'Antenna Exchange').

Note: *This only applies if the antenna is positioned in the part where the diameter is twice the antenna size!*
So when for instance an S06 antenna is positioned in the 6" part of a 6" to 12" reducer, the antenna mode should not be changed. When for example an S10 antenna is placed on a 12" stilling well the antenna mode should also not be changed.

Level check (Tab sheet: Product level)

Use the [Accept Reference] command to initialize the level value of the SmartRadar FlexLine to the given reference level. With this procedure, the SmartRadar FlexLine now measures the reference level and the instrument will follow all relative level changes.
This command will only be accepted when the product level status is <GOOD> and the phase guarding state is unequal to <Turbulence>. This command also puts the SmartRadar FlexLine in accurate level measurement mode, so this command MUST be given!

The [Accept Reference] command can handle either a reference innage or a reference ullage level. To adjust to an innage level fill in entity [Reference innage], to adjust to an ullage level fill in entity [Reference ullage] (see figure 1). In case the initial level of the SmartRadar FlexLine is expected to have a serious deviation, for instance because the SmartRadar FlexLine is situated near the tank wall*) and the product level is close to the bottom, it is highly recommended to perform an ullage dip with respect to radar reference at the position of the SmartRadar FlexLine. This value should then be filled in entity [Radar reference ullage].

*) Near to the tank wall is when distance: antenna – tank wall is:
< 0.2 x [Tank Bottom Position] for F06 antenna
< 0.15 x [Tank Bottom Position] for F08 antenna

The [Accept reference] command can be given when all values are entered and sent to the SmartRadar FlexLine.
When none of the above mentioned entities is known, the [Accept reference] command should be given without filling any of these entities. The SmartRadar FlexLine will now be put in accurate level measurement mode.

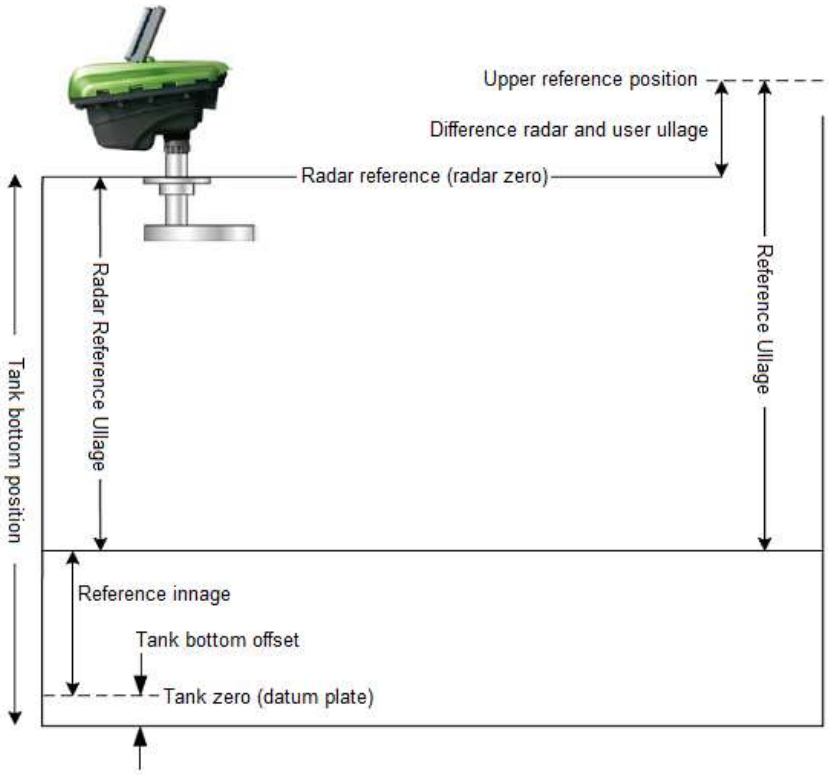

Figure 1 Level check entities

The [Accept reference] command doesn't adjust [Tank bottom position], so this entity should be set manually to approximately the correct value (within ±0.1m). Instead entity [Tank bottom offset] is adjusted. Innage is calculated as:
[Tank bottom position] + [Tank bottom offset] – Radar Ullage (1)

So in the configuration of figure 1 (where tank zero is above the tank bottom) the value of [Tank bottom offset] is negative.

When [Radar reference ullage] and either [Reference ullage] or [Reference innage] are set, the SmartRadar FlexLine will automatically calculate the difference between radar reference and the upper reference position and store this value in entity [Difference radar and user ullage]. When an [Accept reference] command will be given in the future, the SmartRadar FlexLine will automatically use this value to calculate [Radar reference ullage].

So when [Difference radar and user ullage] is available, there is no need to perform an additional ullage dip at the position of the SmartRadar FlexLine. [Difference radar and user ullage] is the difference between radar and user reference. So in the configuration of figure 1 (where upper reference is above radar reference) the value of [Difference radar and user ullage] is negative.

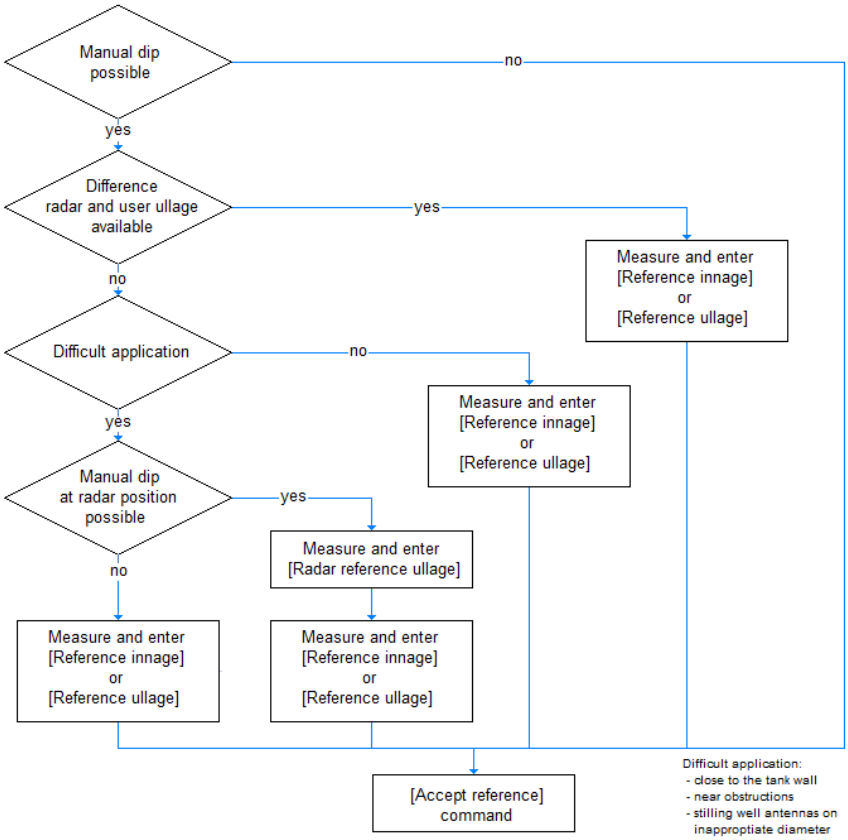

Figure 2 Overview [Accept reference] command

Finally, check [Accept reference status] to see if the command has been accepted. If the status is <Accept reference failed>, the SmartRadar FlexLine has probably an <UNCERTAIN> or <BAD> health status. If the status is <Accept reference not accepted>, the SmartRadar FlexLine is in the <Turbulence> state (see diagnostics ‘Phase guarding’).

When the tank is (almost) empty, there's a good chance the gauge will get in the <Turbulence> state when the product is pumped into the tank for the first time. In that case the Heimdall table won't be build up and a new [Accept reference] command has to be given when there's product in the tank.

Note: *Entities [Tank bottom position] and [Upper reference position] must be set to the correct value before an [Accept reference] command is given.*

Note: *When the SmartRadar is moved to another location entity [Difference radar and user ullage] must be cleared as well as the Heimdall table. The Heimdall table can be cleared by the [Clear Heimdall Table] command. [Difference radar and user ullage] can be cleared by the [Clear difference] command. Don't set [Difference radar and user ullage] to 0, because this is a valid value!*

Engauge

- To make sure the [Accept reference] command works fine all entities must have been sent to the gauge (no yellow backgrounds may be visible) prior to giving the command.
- To read the [Accept reference status] push the [Read] button (is not automatically displayed).
- To clear entity [Difference radar and user ullage] use [Clear difference] command.

SmartView

- When the [Accept reference] command has failed, an "error" message will appear behind the command. When no message is visible, the command has succeeded.
- Because of the limited space on the SmartView display, some entities and statuses are abbreviated:
  - [Radar reference ullage] is shown as [Reference radar] or [Ref. Radar ull.] (from software version A1120).
  - [Accept reference status] is shown as [Reference status] and can be found in the commissioning menu.
  - [Difference radar and user ullage] is shown as [Dif usr radr ull].
  - [Clear difference] command to clear entity [Difference radar and user ullage] is shown as [Clr usr radr ull] in the command menu.
  - Status <Accept reference failed> is shown as <Fail NOK>.
  - Status <Accept reference not accepted> is shown as <Not accp>.

Alarm settings (Tab sheet: Product level)

Similar to basic.

Alarm loop checking (Tab sheet: Product level)

Similar to basic.

Manual overwrite (Tab sheet: Product level)

With a manual overwrite the primary value (innage) can be overwritten by a manual value.

To get a manual value:

Give [Kill measurement] command
Fill in [Manual overwrite] and send it to the gauge.

To return to instrument level press [Resurrect].

Note: *Manual value is only applied to the primary value (innage). The secondary value (ullage) is still an instrument value!*

COMPENSATIONS (TAB SHEET: COMPENSATION)

Compensations can be enabled or disabled by setting the appropriate switches in entity [Compensations and features].

Table 1 Compensation switches

Position	Compensation or feature	Default
1	-	False (Disabled)
2	Compensation by verification pins	False (Disabled)
3	Linear compensation	False (Disabled)
4	Tank shell expansion compensation	False (Disabled)
5	Compensation for hydrostatic deformation	False (Disabled)
6	Moving averaging filter	True (Enabled)
7	Predictive moving averaging filter	False (Disabled)
8	Level end switch	False (Disabled)
9	Maximum safe fill	True (Enabled)

Output filters

The SmartRadar FlexLine can activate an output filter for both radar innage and radar ullage to reduce level noise. The higher the value of the [filter averaging constant], the more damping on the radar innage and radar ullage values. The minimum value of the [filter averaging constant] is 0 (no filtering), the maximum value is 99.95 (99 up to software version A1110).

There's a choice between two types of filters: a 'moving averaging filter' and a 'predictive moving averaging filter'.

The general behaviour of the moving averaging filter is shown in figure 3. The filter introduces a lag between actual ullage/innage and filtered ullage/innage when the product level is changing. The higher the value of the [filter averaging constant], the larger the lag is. Because of the high level update rate of the SmartRadar FlexLine, the lag is relatively small. Table 2 gives an indication of the behaviour for different filtering constants. E.g. when the [filter averaging constant] = 95 and the level change is 0.5 mm per second, the maximum lag will be approximately 2 seconds in time and thus 2*0.5=1 mm in distance while the noise reduction will be approximately 4.5 (level change is 0.02"/sec; maximum lag is 2*0.02"=0.04").

A disadvantage of the moving averaging filter is the lag when the product level is moving. When the product level is moving uniformly the predictive moving averaging filter will eliminate the lag (see figure 4). This means that the output level will be equal to the actual level. The output level will now however have some overshoot when the product level starts and stops moving. Because of the high level update rate of the SmartRadar FlexLine,

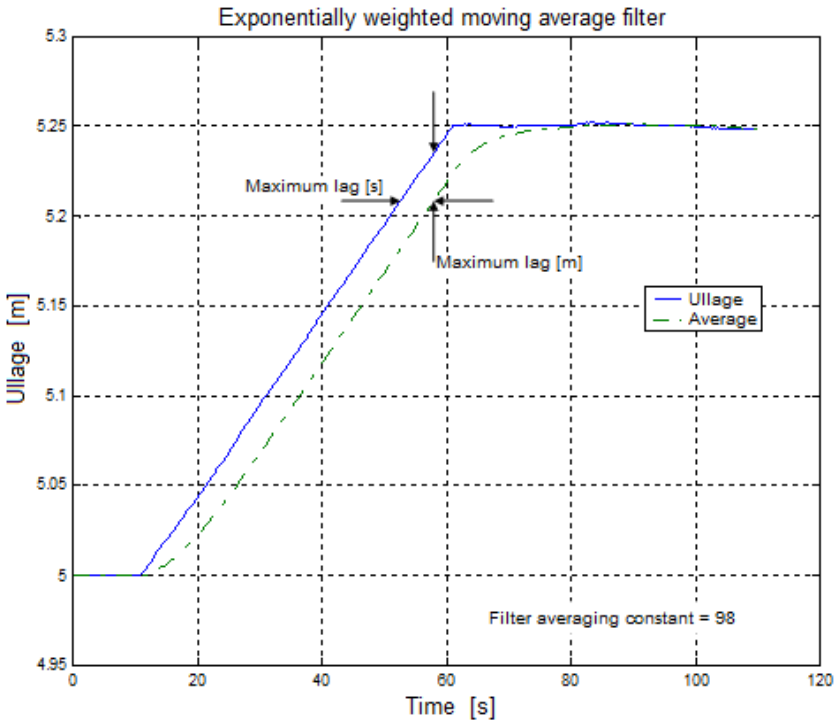

Figure 3 Example of moving average filter behaviour (level change = 5 mm/sec ($^3/_{16}$"/sec))

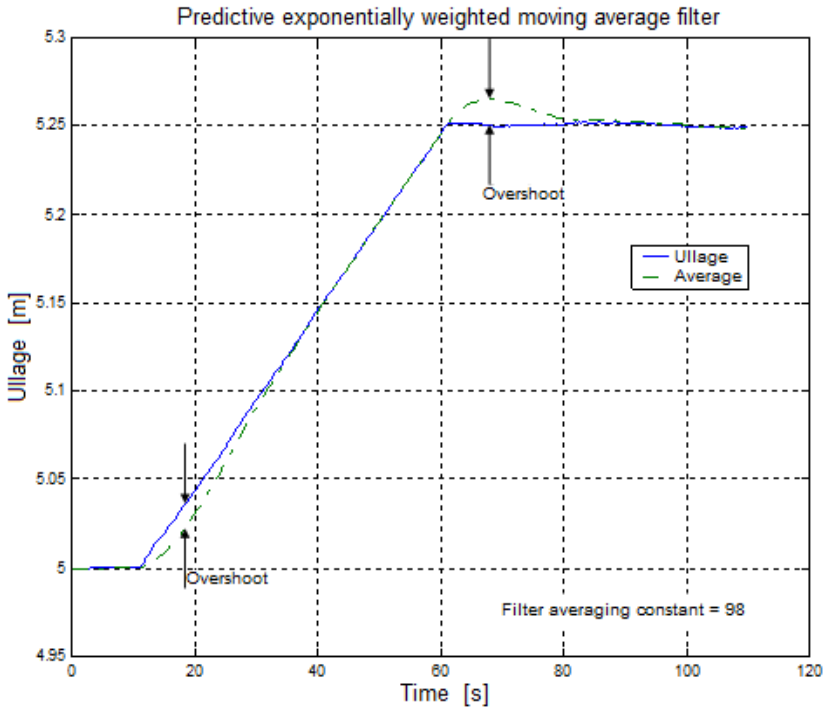

Figure 4 Example of predictive moving average filter behaviour (level change = 5 mm/sec ($^3/_{16}$"/sec))

the overshoot is relatively small. Table 3 gives an indication of the behaviour for different filtering constants. E.g. when the [filter averaging constant] = 98 and the level change is 0.7 mm/sec (0.03”/sec), the overshoot will be approximately 2.9 *0.7 = 2 mm (2.9*0.03” ≈ 0.09”) while the noise reduction will be approximately 7. The output of the filter will return to within 0.1 mm (5% of 2 mm) (0.004” (5% of 0.09”)) of the actual level in approximately 30 seconds, both at the start and end of the pumping.

Only one of both filters can be selected as output filter. When both filters are enabled (both switch 6 and 7 are true) only the ‘moving averaging filter’ is activated.

Table 2 Filter characteristics of moving averaging filter (dL = actual displacement per second)

Filter averaging constant	Approximate noise reduction factor	Maximum lag during pumping [sec]	Maximum lag during pumping (distance)
50	1.4	0.1	0.1 * dL/sec
70	1.8	0.25	0.25 * dL/sec
90	3	1	1 * dL/sec
95	4.5	2	2 * dL/sec
98	7	5.5	5.5 * dL/sec
99	10	11	11 * dL/sec
99.5	14	22	22 * dL/sec
99.8	22	55	55 * dL/sec
99.9	32	110	110 * dL/sec
99.95	45	220	220 * dL/sec

Table 3 Filter characteristics of predictive moving averaging filter (dL = actual displacement per second)

Filter averaging constant	Approximate noise reduction factor	Maximum overshoot	Time to return within 5% of overshoot [sec]
50	1.4	0.1 * dL/sec	1.8
70	1.8	0.2 * dL/sec	3.3
90	3	0.7 * dL/sec	8.3
95	4.5	1.3 * dL/sec	14
98	7	2.9 * dL/sec	29
99	10	4.9 * dL/sec	50
99.5	14	8.2 * dL/sec	90
99.8	22	15.5 * dL/sec	200
99.9	32	25 * dL/sec	400
99.95	45	38 * dL/sec	750

Verification pin compensation

Similar to basic.

Linear compensation

With the linear compensation, ullage can be adjusted by a gain factor and an offset:

*CompensatedUllage = [Gain]*Ullage +Offset* (2)

To enable the linear compensation the 3rd switch of [Compensations and features] should be set to 'True' and the following entities should be set: [Primary value gain] and [Primary value offset].

Note: *Despite their names, [Primary value gain] and [Primary value offset] are NOT affecting innage (primary value) directly. The compensation is applied to ullage!*

Engauge Primary value gain] and [Primary value offset] are to be found on the tab sheet 'Product level'. The switch is to be found on tab sheet 'Compensations'

Tank shell compensation (Gauge reference compensation)

Thermal expansion of the tank shell or stilling well influences the reference position of the SmartRadar. A compensation method shall be applied so that the total deviation for a temperature change of 10°C falls within the maximum permissible error for the installed SmartRadar (according to OIML R85).

Radar ullage is influenced by thermal expansion of the tank shell, but this distance is a 'true' measured value. Hence, the compensation is applied to radar innage. The compensation only takes expansion of the vapour space area of the tank shell into account. The tank shell temperature is not a direct measured parameter. It will therefore be calculated from vapour and ambient temperature.

If the SmartRadar FlexLine is equipped with the average temperature option, the vapour temperature is measured and used in the gauge reference correction calculations. If this temperature value is not available, then a manual value is used. So for the vapour temperature the following quantity is used (in decreasing priority):

Distributed vapour temperature
[Tank Shell manual vapor temperature]
[Tank shell last valid vapor temperature]

As ambient temperature the [Board temperature] can be selected by entity [Tank shell ambient temperature selection]. If this entity is set to 'Ambient temperature manual', the following quantity is used for the ambient temperature (in decreasing priority):

[Tank Shell manual ambient temperature]
[Tank Shell last valid ambient temperature]

To enable the tank shell compensation the 4th switch of [Compensations and features] should be set to 'True' and the following entities should be set:

[Tank shell thermal expansion coefficient]
Expansion coefficient of the tank shell material. (default value is: $10x10^{-6}$m/°C).
Carbon steel: $12x10^{-6}$ m/°C
Stainless steel: $16x10^{-6}$ m/°C

[Tank shell vapour ambient ratio]
Ratio of vapour and ambient temperatures for calculation of the tank shell temperature. Refer to table below for more information on the settings in a particular situation.

[Tank shell ambient temperature selection]
Select board temperature or manual ambient temperature.

[Tank shell reference temperature]
Reference temperature for the tank shell compensation. This should be equal to the tank shell temperature at the time of the [Accept reference] command.

Next to the previous entities the following entities can be programmed when no measured data is available or selected.

[Tank shell manual vapor temperature]
Manual vapour temperature. Health status should be set to <GOOD> or < UNCERTAIN > for this value to be used.

[Tank shell manual ambient temperature]
Manual ambient temperature. Health status should be set to <GOOD> or < UNCERTAIN > for this value to be used.

Table 4 Standard values for [Tank shell vapour ambient ratio]

Tank type	[Tank shell vapour ambient ratio]
Fixed roof tank	0.5
Fixed roof tank with stilling well *)	1
Insulated fixed roof tank	1
Floating roof tank with stilling well *)	0
Floating roof tank without stilling well	0

*) Here is meant that the SmartRadar is installed on the stilling well.
The stilling well must be fixed at the tank bottom or at the first ring of the tank shell. If the stilling well is fixed at the top of the tank, then select the values for entity items [Tank shell vapour ambient ratio] from the tank type without stilling well.

[Tank shell temperature] is calculated as:

{[Tank shell vapor ambient ratio] x [Tank shell used vapor temperature]} +
{1 – [Tank shell vapor ambient ratio]} x [Tank shell used ambient temperature]

(3)

[Tank shell compensation] is calculated as follows:

{[Tank bottom position] – Primary Value} x [Tank shell thermal expansion coefficient] x {[Tank shell temperature] – [Tank shell reference temperature]}

(4)

The flowchart in figure 5 shall be followed to enable the gauge reference compensation (tank shell compensation).

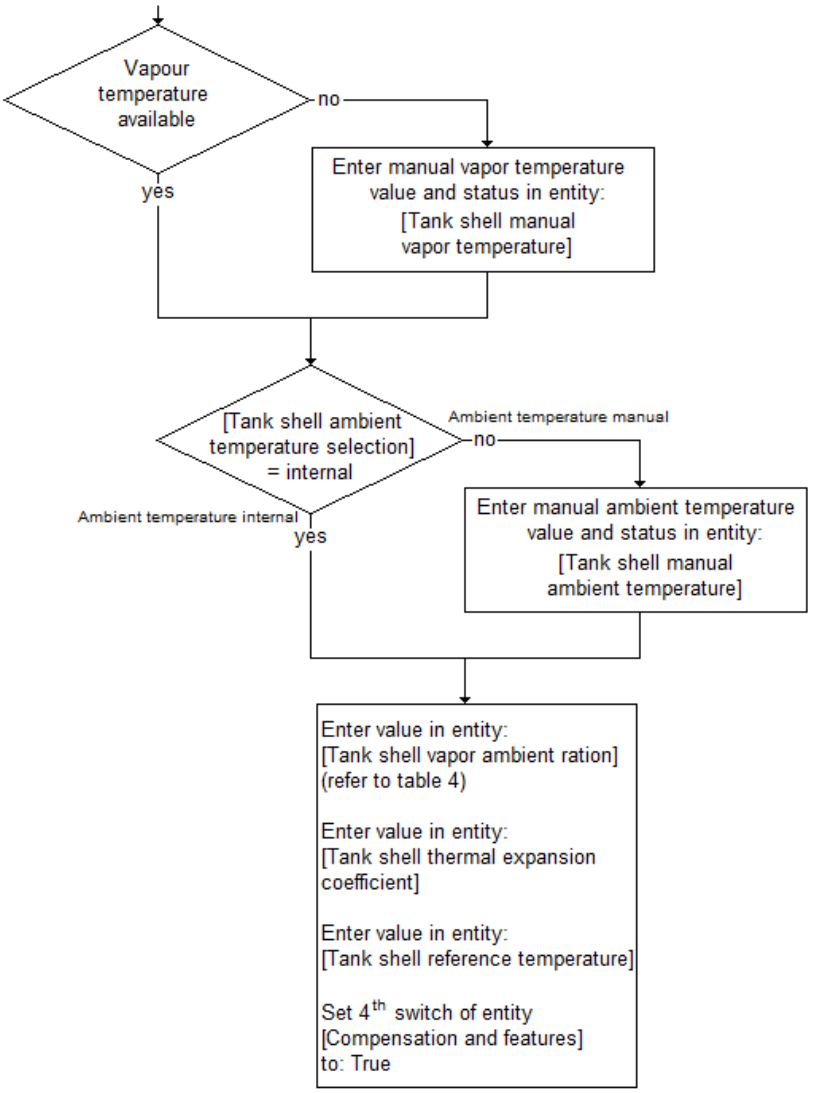
Vapour temperature available
no
yes
Enter manual vapor temperature value and status in entity: [Tank shell manual vapor temperature]
[Tank shell ambient temperature selection] = internal
Ambient temperature manual
no
Ambient temperature internal
yes
Enter manual ambient temperature value and status in entity: [Tank shell manual ambient temperature]
Enter value in entity: [Tank shell vapor ambient ration] (refer to table 4)
Enter value in entity: [Tank shell thermal expansion coefficient]
Enter value in entity: [Tank shell reference temperature]
Set 4th switch of entity [Compensation and features] to: True

Figure 5 Flowchart for gauge reference compensation

Hydrostatic deformation compensation

Due to the liquid pressure on the tank shell, the tank shell will bulge. As a result of this tank shell deformation the tank roof moves downwards. Level gauges, which are installed on roof nozzles of fixed roof tanks, are influenced by this movement. The SmartRadar FlexLine provides an innage compensation for this deformation. This compensation is dependent on the innage level.

To enable the hydrostatic deformation compensation the 5th switch of [Compensations and features] should be set to 'True' and the following entities should be set:

[Hydrostatic deformation factor]
This entity contains the compensation factor in [mm]/m.

[Hydrostatic deformation minimum innage]
This entity contains the innage above which the compensation becomes effective. Below this innage no compensation is applied.

First, the upper reference movement must be found. Then with linear regression, a best fit line can be found as compensation. The outcome of that calculation is used for the [Hydrostatic deformation factor] and [Hydrostatic deformation minimum innage] values.

Calculation of upper reference movement:
With the following formula (according to OIML R 85) the tank shell deformation can be calculated:

$$\delta h = \frac{D \times \rho \times g}{4 \times \mu \times t \times E} \times h^2 \Big|_{h=a}^{h=b} \qquad (5)$$

where

δh	:	tank shell deformation [m]
D	:	tank diameter [m]
ρ	:	product density [kg/m^3]
g	:	local gravity constant [m/s^2]
μ	:	Poisson's constant (for steel μ=3.3)
E	:	modulus of elasticity (for steel E=206.1 x 10^9)
t	:	tank shell (ring) thickness [m]
h	:	distance of the liquid surface with respect to a level below the liquid surface

a and b are e.g. the distances of the liquid surface with respect to the top and bottom of the shell segment under investigation.

If the tank shell thickness and internal diameter remains constant over the total height, a=0 and b equals the innage level.

If the rings have a different plate thickness, each ring has to be calculated individually, where a and b are the distance of the top and bottom welding seam of each individual ring with respect to the liquid surface.
Below follows an example of a calculation for a steel storage tank, diameter 83.82 m, product density of 1000 kg/m3, with the ring heights and wall thickness as per following:

Table 5 Example of tank ring measures

Ring no.	Ring height [m]	Wall thickness [mm]
1	2.743	38.1
2	2.390	36.2
3	2.393	28.9
4	2.390	24.7
5	2.390	20.5
6	2.393	16.3
7	2.390	12.2
8	2.390	11.8
9	2.466	9.5

The local gravity constant is taken as: 9.81288 m/s^2
The deformation per ring is (refer to figure 6 for the calculation of the ullage values per ring):

$$\delta h_{ring\text{-}9} = \frac{83.82 \times 1000 \times 9.81288}{4 \times 3.3 \times 206.1 \times 10^{9}} \times \frac{2.466^2}{9.5 \times 10^{-3}} = 3.0234 \times 10^{-7} \times 640.121 = 0.19 \ [mm] \quad (6)$$

$$\delta h_{ring\text{-}8} = 3.0234 \times 10^{-7} \times \frac{4.856^2 - 2.466^2}{11.8 \times 10^{-3}} = 0.45 \ [mm] \quad (6a)$$

$$\delta h_{ring\text{-}7} = 3.0234 \times 10^{-7} \times \frac{7.246^2 - 4.856^2}{12.2 \times 10^{-3}} = 0.72 \ [mm] \quad (6b)$$

$$\delta h_{ring\text{-}6} = 3.0234 \times 10^{-7} \times \frac{9.639^2 - 7.246^2}{16.3 \times 10^{-3}} = 0.75 \ [mm] \quad (6c)$$

$$\delta h_{ring\text{-}5} = 3.0234 \times 10^{-7} \times \frac{12.029^2 - 9.639^2}{20.5 \times 10^{-3}} = 0.76 \ [mm] \quad (6d)$$

$$\delta h_{ring\text{-}4} = 3.0234 \times 10^{-7} \times \frac{14.419^2 - 12.029^2}{24.7 \times 10^{-3}} = 0.77 \ [mm] \quad (6e)$$

$$\delta h_{ring\text{-}3} = 3.0234 \times 10^{-7} \times \frac{16.812^2 - 14.419^2}{28.9 \times 10^{-3}} = 0.78 \ [mm] \quad (6f)$$

$$\delta h_{ring\text{-}2} = 3.0234 \times 10^{-7} \times \frac{19.202^2 - 16.812^2}{36.2 \times 10^{-3}} = 0.72 \ [mm] \quad (6g)$$

$$\delta h_{ring\text{-}1} = 3.0234 \times 10^{-7} \times \frac{21.945^2 - 19.202^2}{38.1 \times 10^{-3}} = 0.90 \ [mm] \quad (6h)$$

The total tank shell deformation then becomes:

$$\delta h_{21.945} = 0.19 + 0.45 + 0.72 + 0.75 + 0.76 + 0.77 + 0.78 + 0.72 + 0.90 = 6.04 \text{ mm.} \quad (7)$$

The above calculation is for a full tank (level 21.945 m). The tank shell deformation for the same tank, but then with a level of 21 metres is:

$$\delta h_{ring\text{-}9} = 3.0234 \times 10^{-7} \times \frac{1.521^2}{9.5 \times 10^{-3}} = 0.07 \text{ [mm]} \quad (8)$$

Likewise the other ring deformations are to be calculated. If that is done the outcome is:

$$\delta h_{21.000} = 0.07 + 0.33 + 0.61 + 0.67 + 0.70 + 0.72 + 0.73 + 0.68 + 0.85 = 5.36 \text{ mm} \quad (9)$$

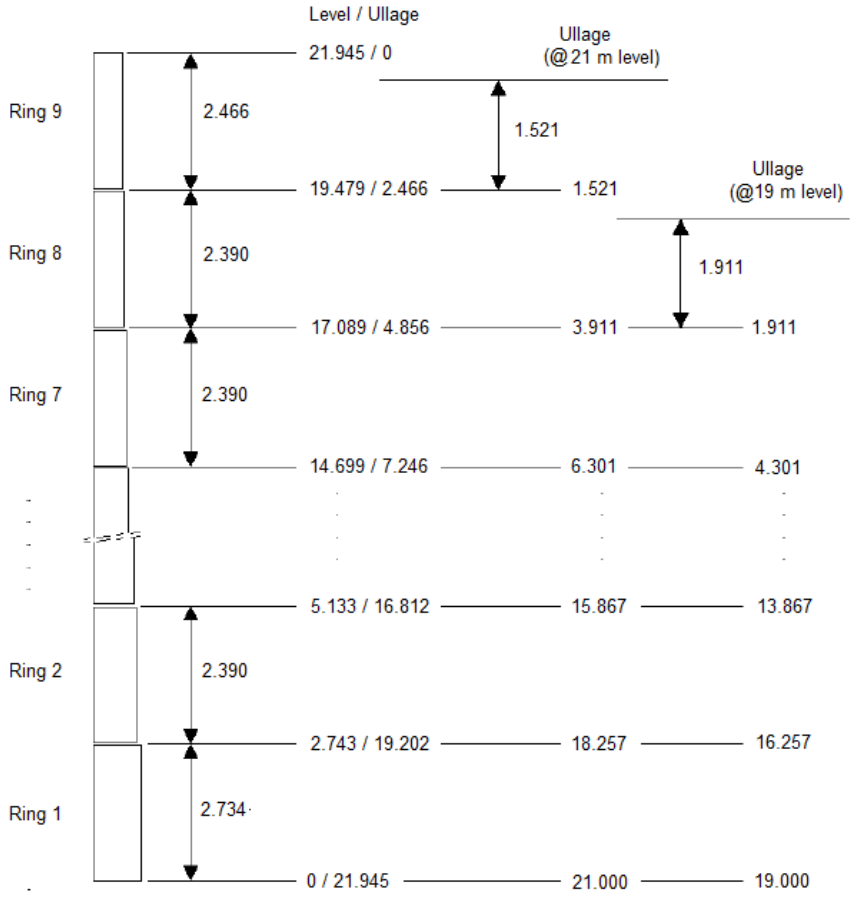

Figure 6 Example steel storage tank with diameter of 83.82 m

The same procedure has to be followed for all different levels, with for instance an interval of 1 meter. Then the following table is obtained:

Table 6 Example of hydrostatic deformation figures					
Level [m]	**Deformation [mm]**	**Level [m]**	**Deformation [mm]**	**Level [m]**	**Deformation [mm]**
0	0	8	0.54	16	2.64
1	0.01	9	0.69	17	3.08
2	0.03	10	0.88	18	3.57
3	0.07	11	1.09	19	4.17
4	0.13	12	1.32	20	4.71
5	0.20	13	1.59	21	5.36
6	0.29	14	1.90	21.945	6.04
7	0.40	15	2.25		

The values in table 6 are the basis for the graph in figure 7.

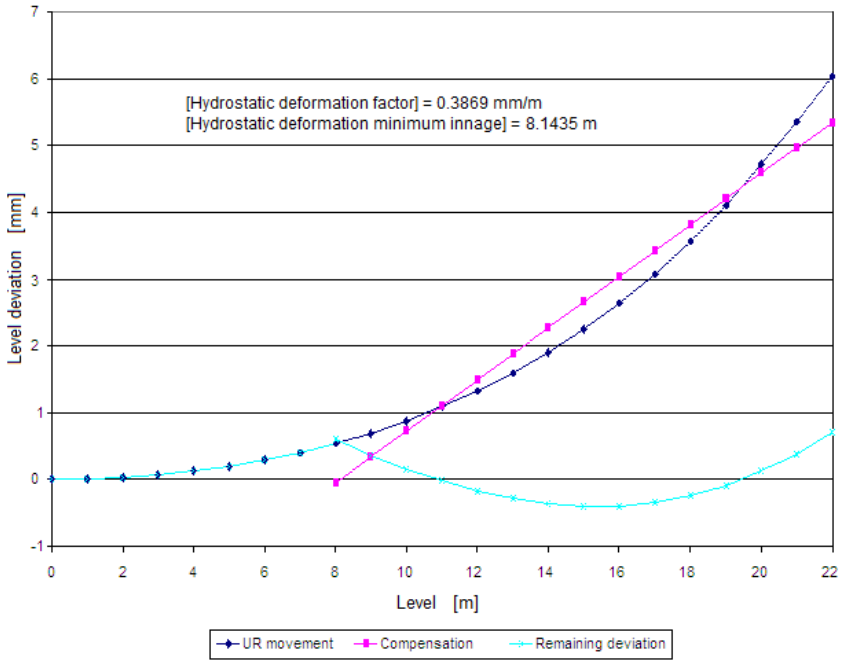

Figure 7 Example of hydrostatic deformation correction

Calculate a regression line from the level where the tank shell deviation is approximately 0.5 mm. In this example, the regression line is calculated from 8 meters level till the maximum level.
Then, the [Hydrostatic deformation factor] becomes: 0.3869 mm/m.
The [Hydrostatic deformation minimum innage] is the point where the regression line crosses the X-axis; in this example at 8.1435 m.

Level end switch

When the level end switch is enabled innage is limited to a minimum value. E.g. default, innage will not be lower than 0.0 when the switch is enabled. When innage is truncated, the weights and measures status is turned off. A hysteresis is implemented to prevent frequent toggling of the weights and measures status.

To enable the level end switch the 8th switch of [Compensations and features] should be set to 'True' and the following entities should be set:

[Level end switch]
This entity determines the level threshold. When innage is lower than -[Level end switch], innage is truncated.
For example, when [Level end switch] = -0.10 m innage will be truncated when it gets below 0.1 m.

[Level end switch hysteresis limit]
Hysteresis limit for the weights and measures status.

When innage is truncated, ullage will be truncated as well to the corresponding ullage value.

Ullage Correction Table

The SmartRadar FlexLine provides ullage dependant compensation on ullage. The ullage correction table is specifically intended for different sections of stilling wells that have different diameters, but is generally usable.

To enable the ullage correction table corresponding 'Distance' and 'Correction' fields must be filled, so no switch has to be enabled. The 'Correction' field contains an offset value that will be applied at the ullage that's entered in the corresponding 'Distance' field. When the ullage correction table has 2 or more entries filled, the compensation at ullages in between will be linearly interpolated (see figure 8).

As soon as a 'Distance' element is found to be zero, it is assumed to be the end of the ullage correction table.

Figure 8 Graphical view of ullage correction table compensation

Note: *Actually, the SmartRadar FlexLine has two ullage correction tables, one for phase ullage and another for PSD ullage (see 'Diagnostics-Heimdall table'). The one for phase ullage is the most important since this one is used when the SmartRadar FlexLine is in accurate level measurement mode. It can be found on the 'Compensation' sheet. The one for PSD ullage can be found on the 'Advanced' sheet. It is advised to use the PSD ullage when a stilling well has sections with different diameters (refer to "Heimdall diagram on stilling well sections with different diameter").*

Maximum safe fill

When the 9th switch of [Compensations and features] is set to 'True' to the SmartRadar FlexLine checks whether innage exceeds [Maximum safe fill], the maximum height the tank can safely be filled. At initial commissioning, [Maximum safe fill] is 0 and must be filled in by the user.

Up to software version A1110

When the 9th switch of [Compensations and features] is set to 'True' the status of the product level will be <UNCERTAIN> when innage exceeds [Maximum safe fill].

From software version A1120

When the 9th switch of [Compensations and features] is set to 'True' the status of the product level will be <BAD> when innage exceeds [Maximum safe fill]. The status will return to <GOOD> when the product level will get below [Maximum safe fill] without exceeding minimum ullage. When minimum ullage is exceeded the status will permanently be set to <BAD> until the user explicitly resets the gauge by giving a [CLEAR_OVERFILL] command when the level is below minimum ullage.

Engauge

- Maximum safe fill is found in the 'Product level' tab.
- The software version can be found in the 'Generic' tab.

SmartView

- Maximum safe fill is found in the commissioning menu as max. safe fill.
- The software version can be found in the identification menu.

DIAGNOSTICS

When the SmartRadar FlexLine gives an inaccurate reading, there are roughly two categories:

- Large errors (>0.15 m)
- Small errors (<0.10 m)

The first category of errors is usually caused by selection of the wrong peak as level peak in the power spectrum. To solve these problems refer to the ‘peak selection’ part of the diagnostics.

In the second category of errors the right peak is selected, but there’s a problem with calculating the product level accurately. On a stilling well application the diameter of the stilling well might be wrong (see Measuring on stilling well). Else, refer to the ‘phase guarding part’ of the diagnostics.

Engauge (from software version A1130)

- The ‘Product level’ tab in Engauge shows a history of the last 10 occurred warning statuses (<UNCERTAIN>) and error statuses (<BAD>).

Peak selection (Tab sheets Peak Selection, Obstructions and zones, Advanced)

All objects that are within the microwave path will cause reflections that will be visible in the power spectrum. Apart from the product reflection, reflections caused by the bottom, antenna and all kinds of obstructions like heating coils, welding seams from tank shell or stilling well can be visible. Also multiple reflections might be visible, for instance additional reflections that travel multiple times between the roof and the product level.

The SmartRadar FlexLine automatically recognizes all kinds of reflection patterns in order to find the correct product peak. But whenever necessary the user can influence the peak selection process by changing certain settings.

Note: *The power spectrum is visualized in the so-called reflection diagram or high resolution reflection diagram. Figure 10 shows an example of a reflection diagram. The reflection diagrams can be made and viewed by the Enraf service tool (Engauge). The high resolution diagram contains 4 times as much data as the ordinary reflection diagram, providing more details.*

Zones and threshold settings

The primary parameter to influence the peak selection is [Relative to highest peak threshold]. This is a threshold that's relative to the amplitude of the strongest peak in the power spectrum. The SmartRadar FlexLine will ignore all peaks that are [Relative to highest peak threshold] dB weaker than the strongest peak. For instance, if the strongest peak is 42 dB and [Relative to highest peak threshold] is at the default value of 16 dB, all peaks weaker than 42 - 16 = 26 dB are ignored. The threshold is valid over the complete measuring range.

For complex situations where the peak selection is not able to find the correct product peak, zones can be used to add additional thresholds. For peak selection, the tank is divided in three measuring zones where individual thresholds can be set: antenna zone, product zone and bottom zone. In addition ten obstruction zones with individual thresholds can be programmed. All these thresholds are absolute. Only peaks that are stronger than these thresholds will be considered as possible product peak.

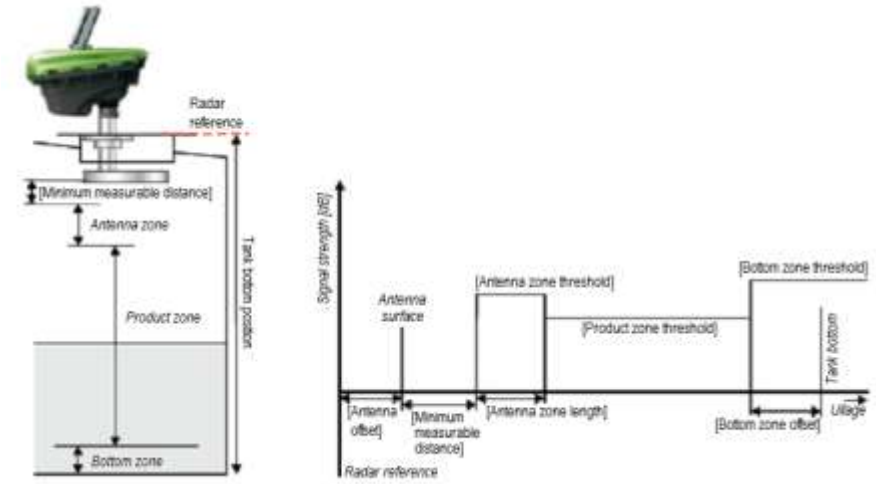

Figure 9 Zones and thresholds

Figure 9 shows the definition of the three zones. Please note that the X-axis is indicating ullage. The zero point on the X-axis represents Radar reference. The antenna zone starts at [Minimum measurable distance] from the antenna. The bottom zone is defined with respect to the tank bottom ([Tank bottom position]). The product zone is the part of the tank between antenna and bottom zone. These zones are also visible in the reflection diagram (see figure 10). Figure 10 also shows [Relative to highest peak threshold], but this threshold is not shown by Engauge up to software version A1122.

Note: *Don't use the [Bottom zone threshold] to mask the reflection of the bottom, unless absolutely necessary. The peak selection uses the bottom reflection (when present) to locate the product peak when the product is near the tank bottom.*

From software version A1130:

The relative threshold is always valid over the complete measuring range, but the actual value depends on the position of the strongest peak. When the strongest peak is positioned in the antenna zone or product zone the value is determined by entity [Relative to highest peak threshold] (default: 16 dB); when the strongest peak is in or beyond the bottom zone the threshold is determined by entity [Relative to highest peak threshold BZone] (default: 16 dB). In case there is a strong reflection from the tank bottom, the entity [Relative to highest peak threshold BZone] can be adapted in order to select the product peak in the bottom zone.

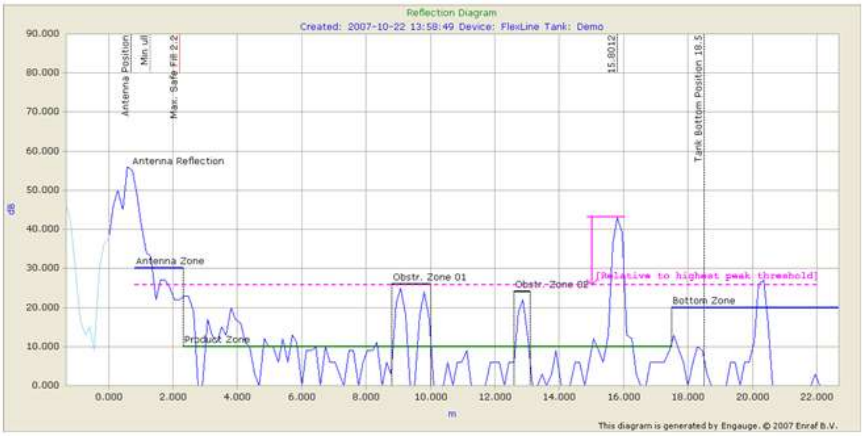

Figure 10 Example of reflection diagram with zones and thresholds
(Relative to highest peak threshold is shown by Engauge from software version A1130)

In case obstructions (e g heating coils) are located in the microwave path, an obstruction zone can be defined to mask the reflection from the obstruction. The position of the obstruction zone and its threshold can be found from the reflection diagram. The ullage and position of the maximum 15 strongest detected peaks can be read in entity [Radar peak diagnostics]. An obstruction zone must be enabled before it becomes effective. The length of the obstruction zone should be at least 0.45m.

An obstruction zones influences the peak selection in two ways:

- It masks reflections below the threshold.

  Peaks below the threshold will not be selected as product peak, except if the peak is identified as product peak in the differential spectrum (see next section).

- It enlarges the margins for tracking the product peak.

The SmartRadar FlexLine keeps track of the product peak with respect to previous measurements. When the product passes an obstruction, wild fluctuations can occur in the location of both product peak and obstruction peak. Using an obstruction zone can enhance peak tracking, especially when the obstruction is strong compared to the product peak.

Note: *When the obstruction peak is stronger than the product peak it will be impossible to measure accurately in the neighbourhood of the obstruction.*

Differential spectrum

The peak selection is not entirely based on the peaks in the power spectrum. The SmartRadar FlexLine also calculates a so-called differential spectrum. In this spectrum, only peaks that change over time will be visible. This is especially useful when the product level is changing or turbulent. Information about the maximum 15 strongest detected peaks in the differential spectrum can be read in entity [Radar peak diagnostics diff]. The differential spectrum has one fixed threshold [Differential spectrum threshold] (default: 30 dB) and a relative threshold which is relative to the highest peak in the differential spectrum [Diff. rel. to highest peak threshold] (default: 20 dB). See also the chapter about “Zones and thresholds” for a description of relative thresholds.

From software version A1130:

The relative threshold is always valid over the complete measuring range, but the actual value depends on the position of the strongest peak. When the strongest peak is positioned in the antenna zone or product zone the value is determined by entity [Diff. rel. to highest peak threshold]; when the strongest peak is in or beyond the bottom zone the threshold is determined by entity [*Diff. rel. to highest peak threshold BZone*] (default: 20 dB).

Note: *The differential spectrum is visualized in the so-called differential spectrum diagram or high resolution differential spectrum diagram. Figure 11 shows an example of a differential spectrum diagram. The differential spectrum diagrams can be made and viewed by the Enraf service tool (Engauge). The differential diagram shows only one threshold which is the highest of the absolute threshold and the relative threshold that is used. The high resolution diagram contains 4 times as much data as the ordinary diagram, providing more details.*

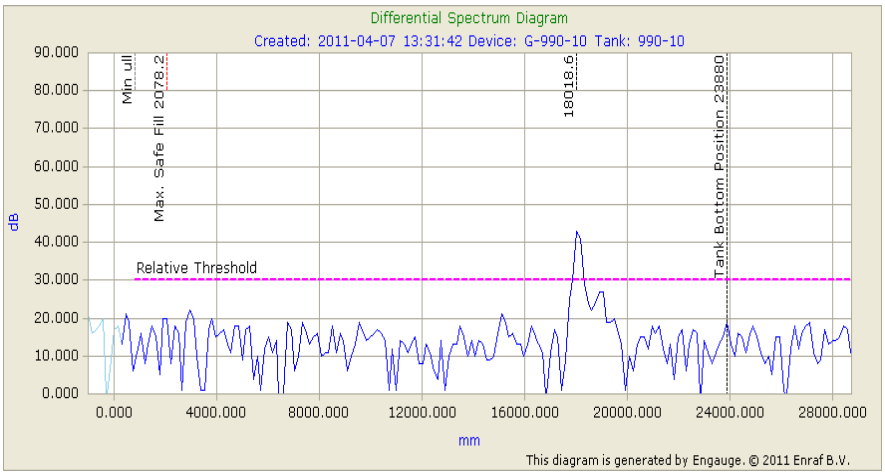

Figure 11 Example of differential spectrum diagram (available from software version A1130)

Additional settings

The SmartRadar FlexLine provides an additional setting to influence the peak selection process (Engauge: tab sheet ‘Peak selection’):

[Peak selection fail delay]

Variations in the reflected signal from the product (product reflection) can cause repetitive low product reflection warnings. With this entity a delay can be set before this warning is generated. During the delay, the last valid measured level is available. If during the delay time a valid product reflection is measured, the delay counter is reset and the measured data is available. If no valid product reflection is obtained after the delay time, a low product reflection warning is generated.

The delay time is not directly in a time unit, but in number of measurements. The SmartRadar FlexLine measures approximately 9 times per second. When [Peak selection fail delay] is set to the default value of 1000, time delay is approximately 110 seconds. The maximum value is 10000, corresponding to approximately 18 minutes.

From software version A1120:

[Preference to first peak]

When this setting is set to true, the peak selection software will have a preference for the first of two strongest peaks when more than one peak is visible in the power spectrum (the first peak is the peak closest to the antenna). When this setting is false (default), the preference is for the furthest peak.

Note: *On stilling well applications unwanted modes cause additional peaks to appear after the main peak. Therefore it is advised to set [Preference to first peak] to true on stilling well applications.*

Diagnostic entities

The SmartRadar FlexLine provides additional information on the peak selection process by the entities described below (Engauge: tab blad ‘Peak selection’). These entities are all ‘freeze’ entities, so the freeze command should be given to get recent data. The freeze command can be omitted if a reflection diagram is recently retrieved, because the freeze command is automatically issued. The peak selection data will then correspond to the latest reflection diagram.

[Selected peak index]
Index of the selected peak in the high resolution power spectrum.

[Confidence level]
Probability of the selected peak. Confidence level varies between 0 and 100. A confidence level of 100 means the selected peak is definitely the right peak. A confidence level lower than 100 means there are other candidates as well.

[Number of detected peaks]
Number of peaks in the high resolution power spectrum above the thresholds.

[Detected peaks]
A list containing the indices of the detected peaks in the power spectrum. The list is ordered by strength. The strongest peak is the first, the weakest the last. For more information on the peaks check [Radar peak diagnostics].

[Radar peak diagnostics]
Information on the detected peaks in the power spectrum. Of special interest is the ‘Classification’ field. This will show information on how the SmartRadar FlexLine evaluates the detected peaks. The Information consists of three parts separated by spaces: {Knowledge source} {Peak classification} {Confidence level}. See classification info for an explanation.

[Detected peaks diff]
A list containing the indices of the detected peaks in the differential spectrum. The list is ordered by strength. The strongest peak is the first, the weakest the last. For more information on the peaks check [Radar peak diagnostics diff].

[Radar peak diagnostics diff]
Information on the detected peaks in the differential spectrum. As with the diagnostics of the power spectrum, the ‘Classification’ field shows information on how the SmartRadar FlexLine evaluates the detected peaks. PSD ullage is not available for peaks in the differential spectrum.

From software version A1130:

[Tracked peak info]
Information on the tracked peak. Suppress counter and suppress state are related to the peak selection fail delay mechanism. Suppress counter shows how many times the tracked peak has not been seen.

Classification info

The classification information consists of three parts separated by spaces:

{Knowledge source} {Peak classification} {Confidence level}

{Knowledge source}: The knowledge source indicates the type of pattern the peak may be part of. The SmartRadar FlexLine has the following knowledge sources:

RFL	The peak is part of a multiple reflection pattern (product or echo). In this case, a pattern of reflections is present that satisfy the conditions (amplitude and distance) of multiple reflections caused by the roof.
BOT	The peak is part of a product and bottom pattern.
OBS	The peak is part of an obstruction.
ANT	The peak is part of an antenna pattern (antenna reflection or antenna echo).
BSP	The peak is not related to another peak.
CLS	The peak is closest to the antenna. This classification info is only possible for peaks in the differential spectrum.

{Peak classification}: The peak classification indicates the type of peak. The SmartRadar FlexLine knows the following types:

PRD	The peak is a possible product reflection.
ANT	The peak is the antenna.
AE	The peak is an antenna echo.
BOT	The peak is the bottom reflection.
OBS	The peak is an obstruction.
ECH	The peak is an echo (multiple reflection).

{Confidence level}: The probability of that particular assumption.

Some examples:

RFL ECH 100	This peak is part of a multiple reflection. It is identified as an echo of the product peak with a 100% probability.
RFL PRD 100	This peak is part of a multiple reflection. It is identified as the first of a series of peaks with a 100% probability.
BSP PRD 082	This peak has no relation to other peaks. It is identified as a possible product peak with an 82% probability.
BOT PRD 100	This peak is part of a product and bottom pattern. It is identified as the product reflection with a 100% probability.
BOT BOT 100	This peak is part of a product and bottom pattern. It is identified as the bottom reflection with a 100% probability.
OBS OBS 100	This peak is in an obstruction zone and is below the threshold of the obstruction zone.
OBS OBS 050 - BSP PRD 009	This peak is in an obstruction zone, but is above the threshold. It is also identified as a possible product peak with a 9% probability.

Phase guarding (Tab sheet Heimdall)

The SmartRadar FlexLine is able to measure level accurately, even under difficult circumstances like close to the tank wall, near obstructions such as heating coils or in stilling well with the wrong diameter. But the SmartRadar FlexLine needs to be in the proper ‘phase guarding state’.
Apart from initialization, the [phase guarding state] is <Guarding>, <Turbulence> or <Recovery>.

[phase guarding state] is <Guarding>

When the [phase guarding state] is <Guarding> it means the SmartRadar FlexLine is in accurate level measurement mode. Product level should be accurate. Check commissioning parameters such as [Stilling well diameter], radar application and Compensations. If these are correct check the Heimdall table for irregularities (see Heimdall table).

[phase guarding state] is <Turbulence>

When the [phase guarding state] is <Turbulence> it means the product level is too turbulent to measure accurately. This can be caused by fast pumping actions or bad weather conditions such as heavy winds on floating roof tanks, especially when the level is low. It can also be caused by unstable peak selection. While the [phase guarding state] is in <Turbulence> it is important to find the cause. There can be three:

- The SmartRadar FlexLine is not able to locate any peaks in the power spectrum.

  In this case the entity [No peaks counter] is increasing steadily. This can be caused by heavy turbulence of the product level or by poor settings of peak selection entities. Check the peak selection entities for high thresholds (*Obstructions and zones*), check the reflection diagram and check for large variations of the [Product peak amplitude] *(Advanced)*.

- The SmartRadar FlexLine switches to another peak regularly.

  In this case the entity [Peaks switched counter] is increasing slowly. There are most likely peak selection problems. Refer to the peak selection part of the diagnostics.

- The phase guarding threshold is exceeded.

  In this case the entity [Δphase above threshold counter] is increasing steadily. This is caused by heavy turbulence of the product level. From software version A1140 it is also possible that the entity [Nr. of sum Δphase above threshold] is increasing. This entity is located at the bottom of the tab sheet.

When the SmartRadar FlexLine is in <Turbulence> it is not possible to perform an [Accept Reference] command or get the gauge in accurate level measurement mode in any other way. Check the Heimdall table for further diagnostics (see Heimdall table).

[phase guarding state] is <Recovery>

When the [phase guarding state] is <Recovery> it means the SmartRadar FlexLine is not in accurate level measurement mode. If the SmartRadar FlexLine has once been put in <Guarding> by the [Accept reference] command, it must have been in <Turbulence> at least once. Check entity [Turbulence state counter] to see how often the SmartRadar FlexLine has been in <Turbulence>. When the [phase guarding state] has entered the <Turbulence> state often, it is important to find the cause. There can be three:

- The SmartRadar FlexLine is not able to locate any peaks in the power spectrum.

  In this case the entity [No peaks counter] is large. This can be caused by heavy turbulence of the product level or by poor settings of peak selection entities. Check the peak selection entities for high thresholds (Obstructions and zones) and check the reflection diagram.

- The SmartRadar FlexLine switches to another peak regularly.

  In this case the entity [Peaks switched counter] is large. There are most likely peak selection problems. Refer to the peak selection part of the diagnostics.

- The phase guarding threshold is exceeded.

  In this case the entity [Δphase above threshold counter] is large. This is caused by heavy turbulence of the product level. From software version A1140 it is also possible that the entity [Nr. of sum Δphase above threshold] is large. This entity is located at the bottom of the tab sheet.

The question is whether the SmartRadar FlexLine is able to get back into guarding. This depends on the amount of valuable data in the Heimdall Table (see Heimdall table).

Heimdall table

The Heimdall table contains the minimum and maximum differences between accurate and PSD ullage. The Heimdall table provides the reference for the accurate level measurement mode. It’s also a valuable diagnostic tool.

When the [phase guarding state] is <Recovery>, the SmartRadar FlexLine can only return to the <Guarding> state automatically when the product level is in a <VALID> part of the Heimdall table. To see whether there's a <VALID> part in the neighbourhood of the present level, compare PSD ullage to the <VALID> parts in the Heimdall overview or take a look at the Heimdall Diagram (Attention: the x-axis of the Heimdall diagram is ullage, not innage).

The ease of returning to the <Guarding> state is determined by the quality of the Heimdall table. This is not only determined by the amount of <VALID> segments, but also by the difference between the minimum and maximum lines. When both are close (within 15 mm) recovery will be easy.

Figure 12 shows a typical example. Between 5.5 and 6.5 m there's a typical obstruction pattern where the difference is quite large and recovery will be hard. From 7 to 16 m is a typical tank wall pattern where the difference is small and an easy recovery is possible.

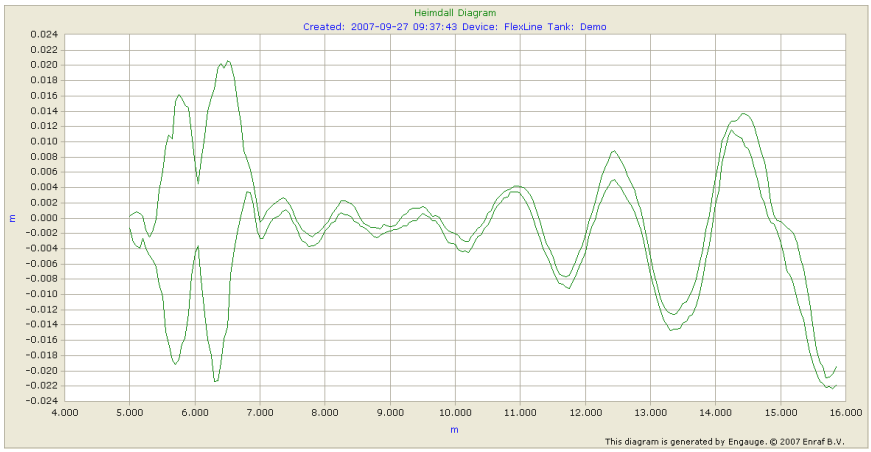
Heimdall Diagram
Created: 2007-09-27 09:37:43 Device: FlexLine Tank: Demo
E
m
This diagram is generated by Engauge. © 2007 Enraf B.V.

Figure 12 Example of Heimdall diagram with <VALID> part

If there is no <VALID> part at all, the SmartRadar FlexLine will not be able to return to accurate level measuring mode at all. In this case, only an [Accept Reference] command will get the SmartRadar FlexLine into the <Guarding> state.

Note: *From software version A1140 the SmartRadar FlexLine stores information acquired from the [Accept Reference] command. This information is used to return to accurate level measuring mode when the radar is around the same level where the [Accept Reference] command was given, even when there are no <VALID> parts at all.*

Figure 13 shows a Heimdall diagram where part of the table is <VALID> (green) and part of the table is <AMBIGUOUS> (red). In the <AMBIGUOUS> part of the table the differences are still recorded, but there's no reference available for the accurate level. To be able to get into the <Guarding> the ullage needs to get into a high quality <VALID> part of the Heimdall table. High quality means that the lines are within 15mm from each other. In this example the parts between 5.0 - 5.3 m and 6.7 - 7.0 m are high quality and the part between 5.3 - 6.7 m is poor quality. When there are no high quality <VALID> elements, the only possibility to get the gauge into the <Guarding> state is an [Accept reference] command.

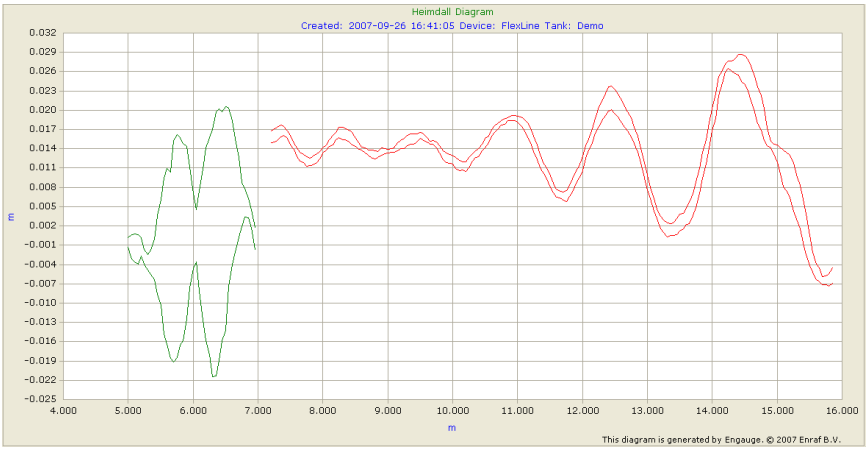

Figure 13 Example of Heimdall diagram with <VALID> and <AMBIGUOUS> part

When an [Accept reference] command is given while the gauge is in the <Recovery> state, all <VALID> parts of the table will be cleared and all <AMBIGUOUS> parts will be made <VALID>. When it's impossible for the SmartRadar FlexLine to build up a proper Heimdall table due to too much turbulence it is advised to build up a Heimdall table by slowly emptying the tank.

Changes to the heimdall table

The Heimdall table can be changed by certain user actions:

- [Accept reference] command when in the <Guarding> state.
  All non-<EMPTY> elements will be set to <VALID>.
- [Accept reference] command when in the < Recovery > state.
  All <VALID> elements will be set to cleared (<EMPTY>).
  All <AMBIGUOUS> elements will be set to <VALID>.

- Change certain entities.
  The Heimdall table will be cleared when the following entities are changed:
  At the ‘Product level’ tab sheet and on the SmartView:
  [Stilling well diameter]
  At the ‘Antenna Exchange’ tab sheet **all** entities *except:*
  [Antenna type], [Minimum measurable distance]
  At the ‘Compensations’ tab sheet:
  [Ullage correction table]
  At the ‘Advanced’ tab sheet:
  [PSD ullage correction table], [Center frequency]
- [Clear Heimdall table] command.
  The Heimdall table will be cleared.
- [Set entities to default] command.
  The Heimdall table will be cleared.

Upgrading the TII-XR with new software will **NOT** clear the Heimdall table.

Heimdall diagram as a diagnostics tool

The Heimdall diagram can be a valuable diagnostic tool and provides a snapshot of all difficulties the SmartRadar FlexLine is facing. When the Heimdall diagram has both <VALID> and <AMBIGUOUS> parts, the dividing line tells where the problems with turbulence or peak selection occur.

The shape of the Heimdall diagram tells a lot about the phenomena the gauge has encountered. Obstructions can be easily identified by their typical pattern (see figure 12 between 5 and 7 m) as well as the influence of the tank wall (see figure 12 between 7 and 16 m).

Heimdall diagram on a stilling well

A special point of attention is the inner diameter of the stilling well. The propagation speed of the microwaves, and hence the level measurement, depends on the inner diameter of the stilling well. Entity [Stilling well diameter] holds the inner diameter of the stilling well. When the real value of the inner diameter differs from the setting in entity [Stilling well diameter], the SmartRadar FlexLine has a scale error in the level measurement. The Heimdall diagram will also show a scale error. The scale error in the Heimdall diagram will be twice as large as the scale error in the level measurement, because both phase ullage and PSD ullage are affected with opposite sign.

So when the Heimdall table has a slope on a stilling well application, it's a strong indication the [Stilling well diameter] is incorrect. The slope of phase ullage has the same sign as the slope of the Heimdall diagram, the slope of PSD ullage has opposite sign

When the slope of the Heimdall table is positive (like in figure 14):

- The slope of phase ullage is positive
- The scale error of phase ullage $\varepsilon_{phase} > 1$
- [Stilling well diameter] has to be increased

When the slope of the Heimdall table is negative:

- The slope of phase ullage is negative
- The scale error of phase ullage $\varepsilon_{phase} < 1$
- [Stilling well diameter] has to be decreased

It is strongly advised to use hand measurements to determine the size of the slope. When these are not or not sufficiently available, the slope can be estimated from the Heimdall diagram and will be approximately half the slope of the Heimdall diagram. When this slope is determined, the new stilling well diameter can be calculated using equation (11) (see Scale error on stilling well).

For example, the slope in the Heimdall diagram of figure 14 is approximately 4 mm on 20 m (the average slope of line 1 over the tops and line 2 under the bottoms). The slope of phase ullage is then approximately 2 mm, the scale error will be approximately

$$\varepsilon_{phase} = \frac{20 + 0.002}{20} = 1.0001 \qquad (10)$$

Figure 14 Heimdall diagram of a 12" stilling well application with wrong [Stilling well diameter]
(line 1 and line 2 are not shown on the Heimdall diagram)

Heimdall diagram on stilling well sections with different diameter

Figure 15 shows the Heimdall diagram of a stilling well application where different sections of the stilling well have slightly different inner diameter. This shows up in the diagram as sections with different slope. Again, it is strongly advised to use hand measurements to determine the size of the slope.

Different inner diameters can't be fixed by changing the inner diameter of the stilling well. Instead Ullage Correction Tables must be used.

For example, there seems to be a slope in the Heimdall diagram of approximately -4 mm from 11 to 22 m. The error in phase ullage is half of that so it will be approximately -2 mm at 22m. The error in PSD ullage will be opposite to that, so it will be +2 mm at 22m. It is advised to correct both phase ullage and PSD ullage by ullage correction table. In this case, the correction will be 0 at 11 m and +0.002 m at 21 m for phase ullage (general Ullage Correction Table, see 'Compensations' sheet in Engauge). The correction will be 0 at 11 m and -0.002 m at 21 m for PSD ullage (Ullage Correction Table PSD, see 'Advanced' sheet in Engauge).

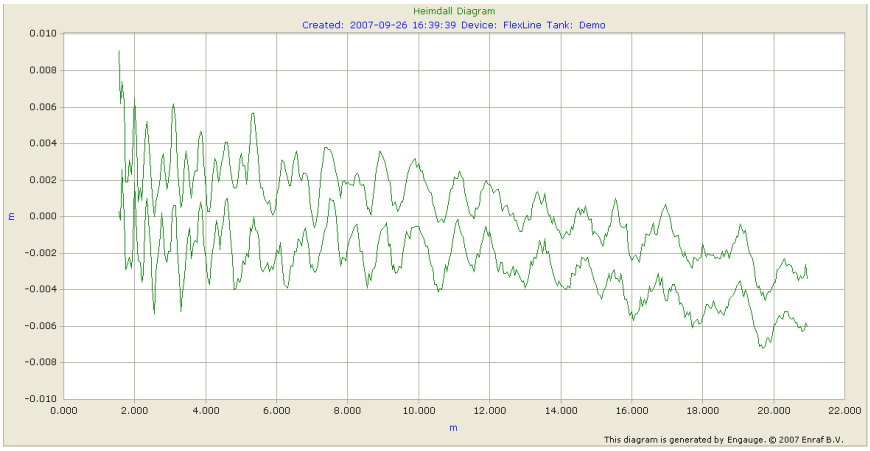

Figure 15 Heimdall diagram of an 8" stilling well application with different sections of stilling well

Raw data diagram

In Engauge a Raw Data Diagram can be made with the FlexLine. It shows the time domain sampled low frequency signal, measured by the FlexLine. On the X-axis, the number of samples (1024) is shown and on the Y-axis the amplitude of the signal. The range on the Y-axis is from -32768 to +32768 (the result from 16 bits AD conversion).
In general the raw data diagram shows a low frequency signal (6 to 12 periods), what is caused by the antenna reflection. Superimposed on that low frequency signal there is a higher frequency, which is caused by the product reflection.
As the antenna reflection is a reflection from nearby (close to the TII-XR unit inside the FlexLine), its amplitude is relatively large. Reflections from further away (such as the product reflection) have a higher frequency and are lower in amplitude.

A good working FlexLine always shows a low frequency component and a higher frequency component in the raw data diagram (refer to figure 16). If there is an abnormality in the sinusoidal wave pattern, for instance (partly) a straight horizontal or vertical line, it is a sign the antenna fails or there is a fail in the TII-XR unit of the FlexLine.

Figure 16 Example of Raw Data Diagram

SCALE ERROR ON STILLING WELL

The propagation speed of the microwaves, and hence the level measurement, depends on the inner diameter of the stilling well. Entity [Stilling well diameter] holds the inner diameter of the stilling well. When the real value of the inner diameter differs from the setting in entity [Stilling well diameter], the SmartRadar FlexLine has a scale error in the level measurement.

It is therefore recommended to check the level reading of the SmartRadar FlexLine with some manual dips at different static levels over the full operating range.

When the SmartRadar FlexLine has a scale error, it's important to know whether the [Phase guarding state] was <Guarding> or <Recovery> during the hand measurements. When the gauge was in <Recovery> mode, PSD ullage has been shown and PSD ullage will behave opposite to phase ullage. When the gauge was in <Recovery>state, use equation (2) to calculate the error of phase ullage. When in doubt about the [Phase guarding state], check the Heimdall diagram (refer to 'Heimdall diagram on a stilling well').

A level scale error, when present, can be corrected in two ways:

- Adjustment of entity [Stilling well diameter] (preferred)
- Ullage correction table

For the correction via the ullage correction table, refer to description of the ullage correction table (see Compensations).

The correct value for the stilling well diameter can be calculated with the following equation:

$$[\text{Stilling well diameter}]_{new} = \frac{a}{\sqrt{1 - \varepsilon_{phase}^2 \times \left(1 - \frac{a^2}{[\text{Stilling well diameter}]_{org}^2}\right)}} \qquad (11)$$

Where

$[\text{Stilling well diameter}]_{new}$ recalculated stilling well diameter [m]

$[\text{Stilling well diameter}]_{org.}$ original stilling well diameter [m] *a* value dependent on antenna mode (see table 7). Engauge: The antenna mode can be found on tab sheet 'Antenna Exchange'

Table 7 Antenna mode value

	TE_{01}	TE_{11}	TE_{02}
a	0.036568	0.017568	0.066952

ε_{phase} scale error of phase ullage. Examples:
a +10 mm error on 20 m range will give a scale error of (20 + 0.010)/20 = 1.0005;
a -15 mm error on 15m range will give a scale error of (15 - 0.015)/15 = 0.999.
Refer to figure 17. It doesn't matter whether innage or ullage levels are used. When (Radar - Reference) is at the Y-axis, scale error ε_{phase} should be larger than 1 when there's a positive slope. The newly calculated [Stilling well diameter] will be larger than the original one. Scale error ε_{phase} should be smaller than 1 when there's a negative slope. The newly calculated [Stilling well diameter] will be smaller than the original one.

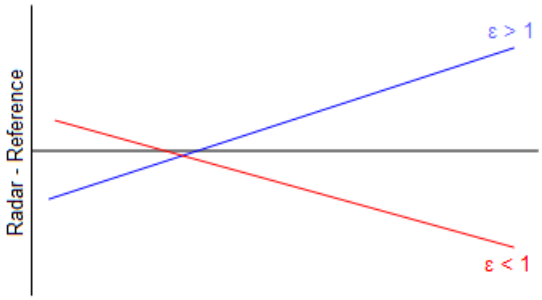

Figure 17 Relation between error and scale error

If radar innage is used on the Y-axis, then the X-axis represents innage. Hence, if radar ullage is used on the Y-axis, then the X-axis represents ullage.

An example with an S10 antenna:

Entity [Stilling well diameter] is programmed as 0.254 m and the antenna mode is TE01. At 2 m the deviation of the SmartRadar FlexLine is -3 mm. At 19 m, the deviation is +2 mm. The new [Stilling well diameter] is calculated as:

$$\varepsilon_{phase} = \frac{17 + 0.005}{17} = 1.000294 \quad (12)$$

$$[\text{Stilling well diameter}]_{new} = \frac{0.036568}{\sqrt{1 - 1.000294^2 \times \left(1 - \frac{0.036568^2}{0.254^2}\right)}} = 0.2576 \text{ [m]} \quad (13)$$

Note: *After the new stilling well diameter is programmed, the SmartRadar FlexLine must (again) be set to level with the [Accept reference] command (see Level check).*

When the SmartRadar FlexLine was in <Recovery> mode during the measurements, the scale error of PSD ullage is measured. The scale error of phase ullage can be calculated by:

$$\varepsilon_{phase} = \frac{1}{\varepsilon_{PSD}} \quad (14)$$

ERRORS AND WARNINGS

The status code of the [Primary value] or the [Secondary value] can display an error (status = <BAD>) or a warning (status = <UNCERTAIN>). Table 8 shows the error numbers and messages that can occur at start-up. Table 9 shows the operational error numbers and messages.

Table 8 Initial error messages

Error number	Error message	Description
1297	Maximum safe fill not set	
1311	EPS centre frequency out of range	
1315	EPS double entries in ullage correction table	
1334	EPS conflict between [Radar application] and [Antenna mode]	Stilling well application but no antenna mode selected or free space application and TE01 or TE02 mode selected.
1335	EPS stilling well diameter out of range	Stilling well diameter out of allowed range (0.04572 – 1.0 m).
1355	Temperature calibration table empty	Empty temperature calibration table. SmartRadar has not been calibrated or NOVRAM has been cleared.
1356	Maximum safe fill not within measuring range	Maximum safe fill is too large. Must be within measuring range of the radar: between [Minimum measurable distance] from antenna and [Tank bottom position].

Table 9 Operational error and warning messages

Error number	Error/Warning message	Description
1298	Level exceeds maximum safe fill	
1299	Tank shell compensation vapour temperature not available	Tank shell compensation is switched on, but no vapour temperature is available.
1300	Tank shell compensation ambient temperature not available	Tank shell compensation is switched on, but no ambient temperature is available.
1316	EPS no peaks detected in the reflection diagram	Check reflection diagram and thresholds.
1321	EPS raw data clipping at the bottom	Set [Automatic gain] to < True > or adjust [Manual gain].
1322	EPS raw data clipping at the top	Set [Automatic gain] to < True > or adjust [Manual gain].
1323	EPS raw data clipping at the top and bottom	Set [Automatic gain] to < True > or adjust [Manual gain].

1324	EPS raw data is almost DC signal	Set [Automatic gain] to < True > or adjust [Manual gain]. When [Actual gain] is maximal (7) there is probably a hardware failure.
1326	EPS too many peaks detected in reflection diagram	Weakest peaks are ignored.
1327	EPS raw data clipping at the top	Set [Automatic gain] to < True > or adjust [Manual gain].
1328	EPS raw data clipping at the bottom	Set [Automatic gain] to < True > or adjust [Manual gain].
1329	EPS raw data clipping at the top and bottom	Set [Automatic gain] to < True > or adjust [Manual gain].
1336	EPS no product peak found in reflection diagram	Check thresholds.
1338	EPS too many peaks detected in differential spectrum	Weakest peaks are ignored.
1349	Radar level end switch exceeded	
1357	Level exceeds maximum measuring range	Minimum ullage has been exceeded. < BAD > health status can only be reset by [CLEAR_OVERFILL] command when level is below minimum ullage.

Engauge

- The error/warning message can be found in the health / status code of the primary and secondary value on the product level tab sheet.

From software version A1130:

- The ‘Product level’ tab shows a history of the last 10 occurred warning statuses (<UNCERTAIN>) and error statuses (<BAD>).

SmartView

- On the SmartView the error number can be found in the commissioning menu by selecting the TII-XR board. The error number is found behind the product level entry.

GENERAL Average temperature & Water level measurement

This section describes the 'advanced' settings which can only be made by the Engauge Professional service tool for the commissioning of the average temperature and water level measurement on the FII-VT board.

VITO Interface and probe types

762 VITO MTT Interface connects:

- 764C VITO temperature probe (16 spots, equally spaced from 1 m (39") above probe bottom end)
- 764D VITO temperature probe (15 spots, equally spaced from 1 m (39") above probe bottom end with additional spot at 0.065 m from probe bottom end)
- 766C VITO combi probe (16 spots, equally spaced from 0.5 m (20") above water probe)
- 766D VITO combi probe (15 spots, equally spaced from 0.5 m (20") above water probe with additional spot at 0.065 m (2.6") from probe bottom end)
- 765 VITO water probe
- 864 MTT

762 VITO LT Interface connects:

- 767C VITO temperature probe (9 spots, equally spaced from 1 m (39") above probe bottom end)
- 767D VITO temperature probe (8 spots, equally spaced from 1 m (39") above probe bottom end with additional spot at 0.065 m from probe bottom end)
- 768C VITO combi probe (9 spots, equally spaced from 0.5 m (20") above water probe)
- 768D VITO combi probe (8 spots, equally spaced from 0.5 m (20") above water probe with additional spot at 0.065 m (2.6") from probe bottom end)
- 765 VITO water probe

762 VITO MRT Interface connects:

- MRT (Multiple Resistance Thermometer) up to 13 temperature elements with one spot element
- MPT (Multiple Pt100 spot elements) up to 14 elements with 2 common wires
- RTD (Resistance Temperature Detector) up to 3 RTD's in 3-wire configuration

Water awareness

If a water probe is connected to the SmartRadar FlexLine (from a combi probe or a separate water probe), the measured water level will be used to check if individual temperature elements are located in the water. If such elements are found, they will be excluded from average product temperature calculation. This is valid for VITO probes, 864 MTT, MPT (Multiple Spot) elements and RTD's. This check cannot be realized with MRT's (Variable Length Elements).

Gauge temperature scale

The FII-VT module supports both international temperature scales IPTS-68 (International Practical Temperature Scale of 1968) and ITS-90 (International Temperature Scale of 1990). The scales apply to °C and Kelvin. The temperature difference between the two scales is illustrated in figure 18.

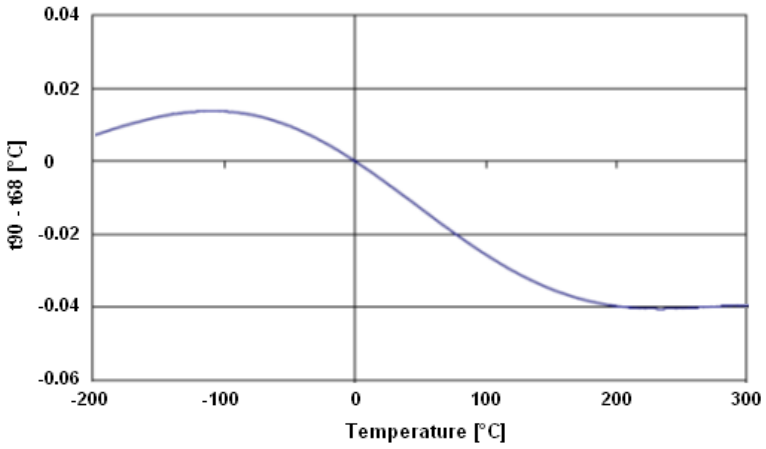

Figure 18 Differences between ITS-90 and IPTS-68

The current element formulas with IPTS-68 coefficients are used and an additional correction is applied to convert to ITS-90.
As the ITS-90 scale is the most recent one, it is therefore the preferred selection.

The entity [Gauge temperature scale] is located on Engauge tab sheet: **Board specific** and can be set to <ITS-90> (default) or <IPTS-68>.

Median filter for each calculated spot temperature

The function of the Median filter is to avoid strong fluctuations in the temperature reading. With the window size of 5, the actual temperature value and the 4 previous values are sorted on ascending value. The actual value will be the middle sorted value. After this, the values are shifted for the next cycle.

The entity [Median filter] is located on Engauge tab sheet: **Product temperature** and can be set to <enable> (default) or <disable>.

Averaging filter for product temperature and vapour temperature

To avoid strong fluctuations in the average product and average vapour temperature values, an averaging filter is implemented. The filter constant can be adapted. The filter constant relation is as follows

$$T_{new} = [Averaging\ constant] * T_{old} + (1 - [Averaging\ constant]) * T_{new} \quad (15)$$

The entities [Average constant filter] and [Average constant] are located on Engauge tab sheet: **Product temperature**.

- The Average constant filter can be set to <enable> (default) or <disable>.
- The Average constant is a value ranging <0 .. x.x> (floating point format). Default value is <0.9>.

Averaging temperature calculation method for product and vapour temperature

This is valid for RTD's, MPT (Multiple Spot) elements, VITO probes and MTT. With entity [Temperature calculation method], under Engauge tab sheet: **Product temperature**, a selection can be made between the following calculation methods:

<Standard>
<Enhanced> (default)
<Custom>

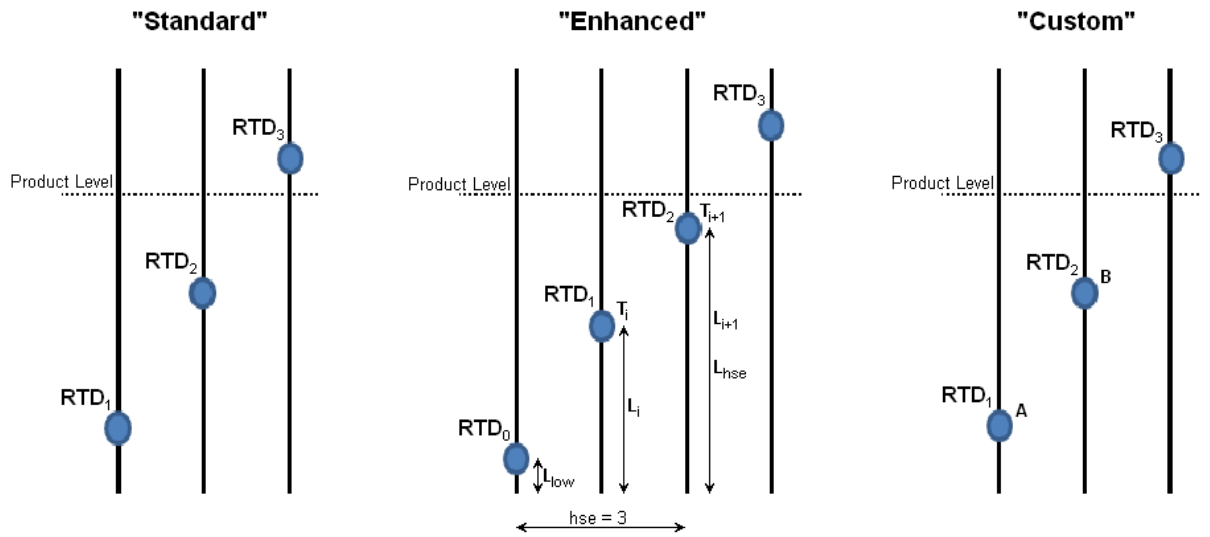

Figure 19 Averaging algorithms

$$T_{ap} = \frac{T_1 + T_2}{2} \quad (16)$$

$$T_{ap} = \sum_{i=0}^{hse} \frac{T_{i+1} + T_i}{2} * \frac{L_{i+1} - L_i}{L_{hse} - L_{low}} \quad (17)$$

$$T_{ap} = \frac{A}{A+B} * T_1 + \frac{B}{A+B} * T_2 \quad (18)$$

Standard averaging:
A straight forward averaging is applied (i.e number of submerged temperatures divided by number of submerged elements).

Enhanced averaging:
The weighing of the individual spots depends on the height of the product level.

Custom averaging:
Includes weighing factors (A, B, etc.) for each individual spot. Intended to be used for non-cylindrical tanks.
The weighing factors are configurable.

Where:

T_{ap} = Average product temperature
T_1 = Temperature of element (RTD) 1
T_2 = Temperature of element (RTD) 2
A = Weighing factor of element (RTD) 1
B = Weighing factor of element (RTD) 2
hse = highest selected element (RTD) in product
low = lowest element (RTD) in product
L_i = position from bottom of i^{th} element (RTD)
T_i = temperature of i^{th} element (RTD)

When the 'Custom' average temperature calculation method is selected, the 'weighing factors' must be entered.

As an example, a sphere with a 767**C** VITO LT probe. With the entities [Lowest element offset] and [Sensor length], the distances midway the elements L_1, L_2, etc. can be calculated.

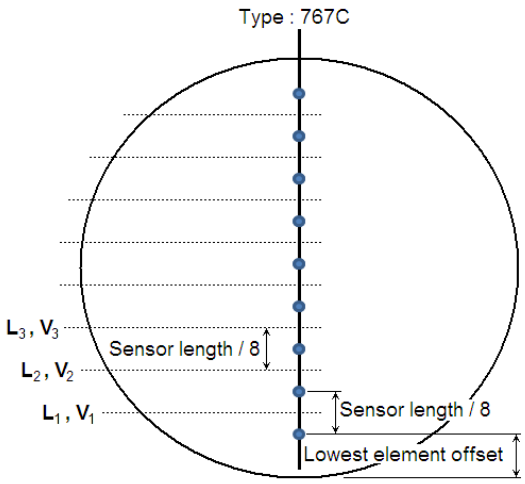

Figure 20 Weighing factors with sphere

From the Tank Capacity Table, the corresponding volumes V_1, V_2, etc. are obtained. The weighing factors are then being calculated as:

$$A = 1, \quad B = \frac{V_2 - V_1}{V_1}, \quad C = \frac{V_3 - V_2}{V_1}, \text{ etc.} \qquad (19)$$

Example:
In a sphere with diameter of 18.620 m (61.089 ft), a VITO probe model 767**C** (lowest element located 1 m (3.281 ft) from bottom of probe and the position of the highest element is at 17 m (55.774 ft) (refer to figure 21).

The lowest element offset in this example is 1 m (3.281 ft).
Then the Sensor length is calculated as follows:

Sensor length = Position highest element – lowest element offset
= 17 m – 1 m (55.774 ft – 3.281 ft)
= 16 m (52.493 ft) (20)

The element interval is calculated as:

Element interval = Sensor length / 8
= 16 m / 8 (52.493 ft / 8)
= 2.000 m (6.562 ft) (21)

The distances midways the elements (L_1, L_2, etc.) can now be found:

L_1 = Lowest element offset + Element interval / 2 (22)
$L_2 = L_1$ + Element interval (22a)
$L_3 = L_2$ + Element interval (22b)

The values are listed in table 10.

The volumes V_1, V_2, etc. are found from the Tank Capacity Table.

The weighing factors are calculated as:
A = 1
B = (V2 – V1) / V1 (19)
B = (400.951 m^3 - 108.615 m^3) / 108.615 m^3
B = 2.6915
or
B = (2521.91 bbl – 683.17 bbl) / 683.17 bbl
B = 2.6915
etc.

In table 10 are listed:

- midway distances
- corresponding volumes from the Tank Capacity Table
- calculated weighing factors.

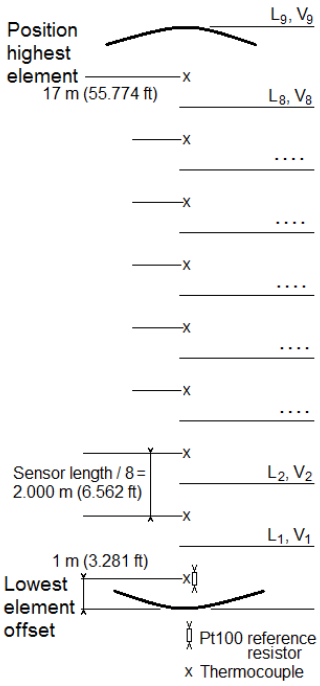

Figure 21 Example weighing factor calculation sphere with VITO probe

Table 10 Example of weighing factors with sphere D = 18.62 m (61.089 ft) and VITO probe model 767C

n	Level		Volume		Weighing factors
	m	ft	m^3	bbl	
1	2.000	6.562	108.615	683.17	A = 1
2	4.000	13.123	400.951	2521.91	B = 2.6915
3	6.000	19.685	826.742	5200.05	C = 3.9202
4	8.000	26.247	1335.721	8401.44	D = 4.6861
5	10.000	32.808	1877.625	11809.91	E = 4.9892
6	12.000	39.370	2402.187	15109.30	F = 4.8295
7	14.000	45.932	2859.143	17983.47	G = 4.2071
8	16.000	52.493	3198.225	20116.23	H = 3.1219
9	18.620	61.089	3380.163	21260.59	I = 1.6751

The entity [Element weighing factor] is located on Engauge tab sheet: **Board specific** and contains 16 data fields ranging: <0 .. +x.x> (floating point format). Default value is <1>.

Note: *Only* ***actually used*** *elements are to be entered*

Range checking and element skipping

A range check mechanism is built in to detect if a temperature element is used outside the specified temperature range. In case the element is outside the range, the temperature status is set to fail. The temperature range on which is checked depends on the selected element type.

Table 11 Temperature element range

Element type	Low probe temp. range	High probe temp. range
Pt100 large, VITO probes	-200 °C (-328 °F)	250 °C (482 °F)
Pt100 small, Ni191, PtCu100, Cu100	-20 °C (-4 °F)	120 °C (248 °F)
Cu90 Enraf, Cu90 Beacon, Cu90 Nulectrohm Sangamo MRT, Sangamo spot	-100 °C (-148 °F)	280 °C (536 °F)

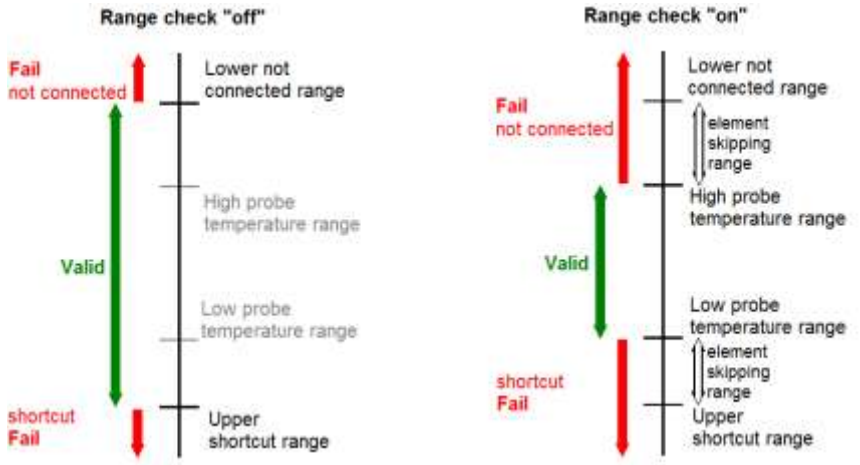

Figure 22 Range checking and element skipping

If the range check is disabled (default), the temperature element is set to fail if a resistance ≤Upper shortcut range (short cut) or ≥Lower not connected range (interrupted) is detected.

With the range check enabled, this fail range decreased to ≤Low probe temperature range (short cut) or ≥High probe temperature range (interrupted). The area between Low probe temp. range – Upper shortcut range and High probe temp. range – Lower not connected range is used as element skipping range.
If a temperature element is found within the element skipping range, it will not be used for average product temperature calculation or average vapour temperature calculation. The maximum number of skipped elements is: 2 (default 1).

The entities [Temperature range check] , [Element skipping] and [Maximum skipped elements] are located on Engauge tab sheet: **Product temperature**.

- The Temperature range check can be set to <enable> or <disable> (default).
- The Element skipping can be set to <enable> or <disable> (default).

Note: *Element skipping is only effective when [Temperature range check] is enabled.*

The Maximum skipped elements is a number which can be 1 (default) or 2.

For W&M purposes, the Lower temperature range and Higher temperature range can be adapted.

The entities [Low probe temperature range] and [High probe temperature range] are located on Engauge tab sheet: **Board specific**.

- The Low probe temperature range is a value ranging: <-x.x to +x.x> (floating point format). Default value is <0>.
- The High probe temperature range is a value ranging: <-x.x to +x.x> (floating point format). Default value is <0>.

Element wiring

One (or more) spots can be disabled from average product temperature calculation. This is set in entity [Element wiring], by placing a non-zero (≠ 0) at the position of the element that needs to be excluded. For instance, to disable the lowest spot element [Element wiring] is set: F000000000000000

The entity Element wiring is located on Engauge tab sheet: **Product temperature**.
The Element wiring is a field of 16 hexa-decimal characters. A non-zero (≠ 0) character at position **x** results in element **x** being excluded from calculation.
Default setting is: <0000000000000000>.

Low level behaviour

The low level behaviour defines how to determine temperature and temperature status in case the product level drops below the lowest element used in temperature calculation.

The low level behaviour can be set to:

- Fail (default)
- Use last valid temperature
- Use lowest element (T1)
- Use second element (T2)

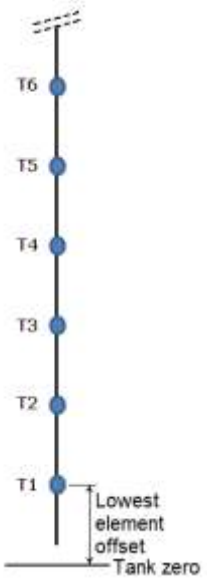

Figure 23 Low level behaviour

Low element usage

According to international recommendations (API and ISO) for temperature measurement in storage tanks, temperature shall be measured starting from 1 m (3 ft) above the tank bottom. The VITO probes model C (764**C**, 766**C**, 767**C** and 768**C**) fulfill this requirement by having the first element at 1 m from the probes bottom end. However, when tanks are operated at a lower level than 1 m (3 ft), an extra spot can be located at a lower level, which then is only used when the level drops below 1 m (3 ft.). The spot below 1m (3 ft.) shall not be used for the average temperature measurement when the product level is above 1 m (3 ft.). For that purpose VITO probes model D (764**D**, 766**D**, 767**D** and 768**D**) do have one additional element at the bottom of the probe.
For the VITO probes model D and MPT (Multiple Spot) probes with a temperature element below 1 m, the low element usage needs to be configured. The low element usage defines which elements are included in the temperature calculation. There are the following choices:

- No exclusion (default); all submerged elements are used (not API compliant)
- Static exclusion; all submerged elements above the [temperature element exclude zone]; without lowest element.
- Dynamic exclusion; dynamical with smoothing lowest element will be used at low product levels only.

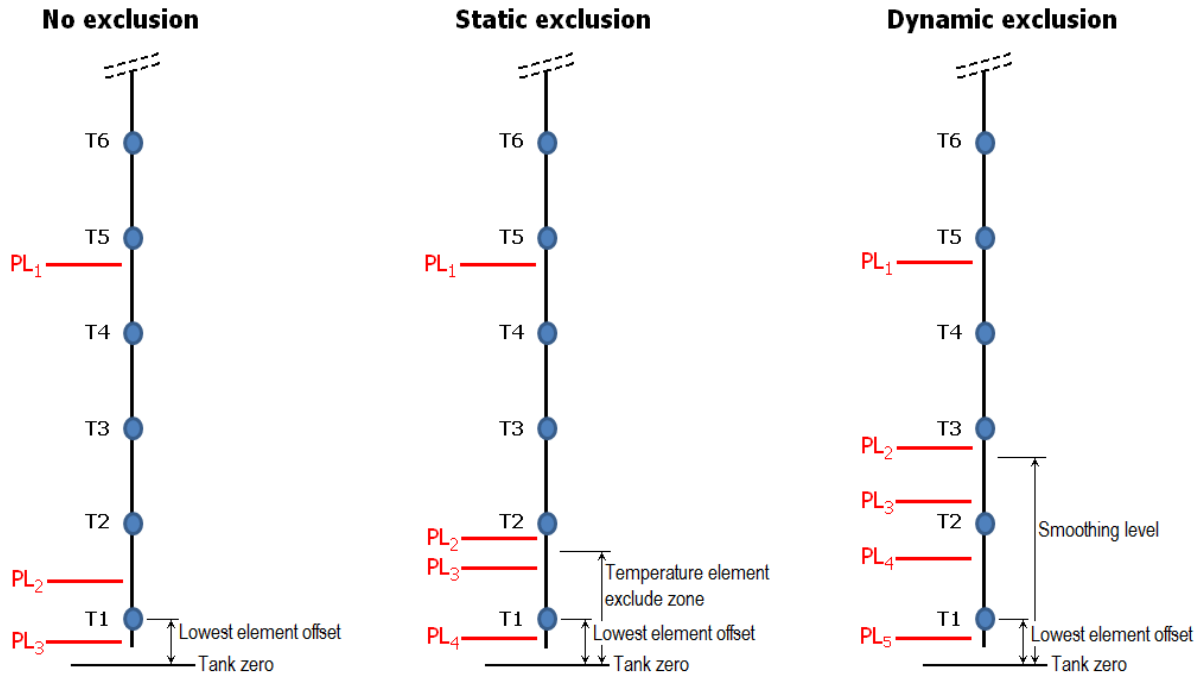

Figure 24 Low element usage

Average product temperature calculation uses at
- Product level 1 (PL_1): T1, T2, T3 and T4
- Product level 2 (PL_2): T1
- Product level 3 (PL_3): [Low level behavior] setting on T1

Average product temperature calculation uses at
- Product level 1 (PL_1): T2, T3 and T4
- Product level 2 (PL_2): [Low level behavior] setting on T2
- Product level 3 (PL_3): temperature fail
- Product level 4 (PL_4): temperature fail

Average product temperature calculation uses at
- Product level 1 (PL_1): T2, T3 and T4
- Product level 2 (PL_2): T2
- Product level 3 (PL_3): smoothing using T1 and T2
- Product level 4 (PL_4): T1
- Product level 5 (PL_5): [Low level behavior] setting on T1

With Dynamic exclusion a smooth change is realized when switching from T2 to T1. When the product level drops from [smoothing level] to T2 position, the average product temperature uses T2 and T1 to the ratio product level and T2 – T3 distance according to the following formula:

$$T_{ap} = \frac{PL_3 - E_2}{E_3 - E_2} \times T2 + \frac{E_3 - PL_3}{E_3 - E_2} \times T1 \qquad (23)$$

Where:

T_{ap} = average product temperature
E_2 = position element 2
E_3 = position element 3
T1 = temperature element 1
T2 = temperature element 2

The closer the product level comes to T2, the higher the influence from T1. When T2 is not selected anymore for average product temperature, then the change to T1 is smooth.

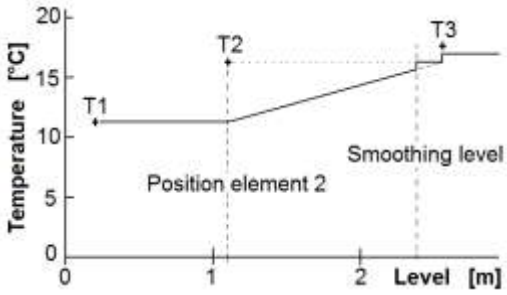

Figure 25 Smoothing

For simplicity reasons, the effect of the [Product immersion depth] and [Hysteresis] are ignored. Smoothing overrules the selected temperature calculation method (standard, enhanced, custom).

The entities [Low level behaviour], [Low element usage], [Temperature element exclude zone] and [Smoothing level] are located on Engauge tab sheet: **Product temperature**.

- The Low level behaviour can be set to :
  - <Temp to fail> (default)
  - <Temp to last fail>
  - <Temp use first element>
  - <Temp use second element>
- The Low element usage can be set to (refer to figure 17):
  - <No exclusion> (default)
  - <Static exclusion>
  - <Dynamic exclusion>
- The Temperature element exclude zone sets the threshold below which a 'temperature fail' is generated when Low element usage is set to 'Static exclusion' and is a value ranging: <-x.x .. +x.x> (floating point format). T1 pos. < [Temp. Element exclude zone] < T2 pos. Default value is <1>.
- The Smoothing level is used when Low element usage is set to 'Dynamic exclusion' (refer to figure 25) and is a value ranging: <-x.x .. +x.x> (floating point format). Below the Smoothing level till Position of element 2, the average product temperature gradually changes to T1 value. T2 pos. < [Smoothing level] < T3 pos. Default value is <0>.

MRT type

Variable Length Elements (or Multiple Resistance Thermometers) can have a spot element at the bottom part (will be switched on from 0.25 m element length). If no spot element is present, the first element is switched on from 0.65 m. Without spot element, the maximum number of MRT elements remains 13.

The entity [MRT type] is located on Engauge tab sheet: **Product temperature** and can be set to:

- <No spot below> (default)
- <With spot below>

MPT element position mode

When the Multiple Spot (MPT) element position mode is set to 'Automatically' (default), the FII-VT software calculates the element positions from the entities: [Sensor length], [Number of elements] and [Lowest element offset]. This method can be used when the elements are placed equidistant. If that is not the case, the element positions must be entered manually. Then MPT element position mode must be set to: Manually. The element positions can be entered in entity: RTD element position.

The entity [MPT element position mode] is located on Engauge tab sheet: **Board specific** and can be set to:

- <Automatically> (default)
- <Manually>

The entity [RTD element position] is located on Engauge tab sheet: **Product temperature** and is a value ranging: <-x.x .. +x.x> (floating point format). Default value is <0>.

Note: *Only* ***actually used*** *elements to be entered.*

Element offset

When the element positions are automatically calculated, each element can be given an offset to this automatically calculated position.

The entity [Element offset] is located on Engauge tab sheet: **Board specific** and is a value ranging: <-x.x .. +x.x> (floating point format). Default value is <0>.

MEASURED DATA Average product temperature

The following measured (calculated) date is available:

On Engauge tab sheet: **Board specific**:

Table 12 Measured data average product temperature - 1	
Name	**Explanation**
[Raw temperature elements]	An array of 16 data fields with the raw (unfiltered) temperatures of each temperature element.
[Raw resistance elements]	An array of 16 data fields with the raw (measured) resistances of each temperature element (only with Variable Length elements (MRT) and Multiple Spot elements (MPT).
[Test resistance]	The measured value of the test resistance in the VITO Interface unit. This value should be: 166.5 Ω ± 0.03%.
[Cable resistance]	The measured cable resistance (black wires) of Variable Length elements (MRT) and Multiple Spot elements (MPT).

On Engauge tab sheet: **Product temperature**:

Table 13 Measured data average product temperature - 2	
Name	**Explanation**
[Element position for calculation]	An array of 16 data fields containing the element positions, including the [Lowest element offset].
[Highest selected element]	The highest selected temperature element for average product temperature calculation.
[Element in calculation]	An array of 16 data fields with information which elements are used for average product temperature calculation.
[Element wiring request]	16 Hexa-decimal characters, showing the sequence in which order the thermo-couples of the VITO probe are connected to the VITO Interface unit.

On Engauge tab sheet: **Miscellaneous**:

Table 14 Measured data average product temperature - 3	
Name	**Explanation**
[HART communication retry counter]	An array of 16 data fields containing the number of HART communication retries with the VITO Interface unit.
[HART detected addresses]	The VITO MTT and VITO MRT Interface unit have HART address 5; the VITO LT Interface unit has HART address 6.
[HART detected device]	The detected type of temperature probe, connected to the VITO Interface unit.
[VITO standard deviation]	A floating point number, containing the standard deviation on 20 resistance measurements on one of the probe wires. Should be < 0.5E-10.
[VITO MTT resistance PT100]	The measured Pt100 resistance of the VITO MTT of VITO LT probe (units: Ω).

MEASURED DATA Average vapour temperature

The following measured (calculated) date is available:

On Engauge tab sheet: **Vapour temperature**:

Table 15 Measured data average vapour temperature

Name	Explanation
[Lowest selected element]	The lowest selected temperature element for average vapour temperature calculation.
[Element in calculation]	An array of 16 data fields with information which elements are used for average vapour temperature calculation.

Water threshold

The water threshold (default 0.01 m) is a distance that minimal needs to be covered with water, before a water level is indicated.

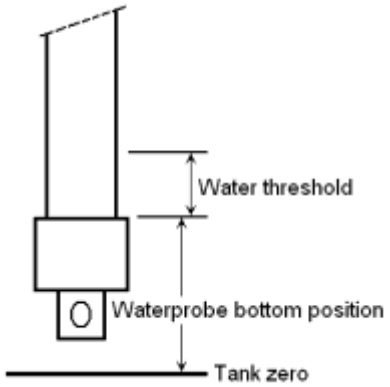

Figure 26 Water threshold

The entity [Water threshold] is located on Engauge tab sheet: **Water level** and is a value ranging: <-x.x .. +x.x> (floating point format). Default value is <0.01>.

MEASURED DATA Water level

The following measured (calculated) date is available:

On Engauge tab sheet: **Water level**:

Table 16 Measured data water level

Name	Explanation
[Measured water capacitance]	Indicates the measured capacitance of the water probe. The value must be in range between [Minimum water capacity] and [Maximum water capacity] (units: pF).

CALIBRATION Water bottom probe

Make sure the VITO water (and temperature) probe is installed properly (refer to installation guide VITO). Factory calibration values for the Maximum water capacity and Minimum water capacity are listed on the "Checklist 765/766/768 Final Assembly", delivered with every VITO probe. The factory calibration value for the Minimum water capacity is obtained by a measurement in air. The measured capacitance depends on the dielectric properties of the product. The dielectric constant for air is 1.
A general value for dielectric constant of oil products is in the area of 1.8 – 2.5. For a 0.5 m (1' 7" $^{11}/_{16}$) long water probe that results in a change in minimum capacitance of 3 – 6 pF, which will cause 5 – 9 mm ($^{3}/_{16}$ – $^{6}/_{16}$) water level deviation. Therefore, the minimum water capacitance must be determined when the probe is installed and completely, or partly, covered by product.

In the following 3 situations the water probe can be calibrated:

- Situation 1: Probe fully covered by product
- Situation 2: Probe partly covered by water and for the remaining part covered by product
- Situation 3: Probe partly covered by product and for the remaining part covered by air.

In all other situations, no calibration can be made.

Situation 1 (probe fully covered by product)
Read the entity [Measured water capacitance] and enter that value into entity: [Minimum water capacity].

Situation 2 (probe partly covered by water and for the remaining part covered by product)
Check by means of a manual dip, the water level.
An interpolation is applied on the [Measured water capacitance] to find the [Minimum water capacity]. Refer to figure 27.

The interpolation is done as follows:

$$\% \text{ of water} = \frac{\text{Water level} - \text{Waterprobe bottom position}}{\text{Waterprobe length}} \times 100\% \qquad (24)$$

If we assume the following numbers as an example:
[Waterprobe bottom position] = 25 mm (or 0.98 inch or 0.082 ft)
[Waterprobe length] = 485 mm (or 19.09 inch or 1.591 ft)
Water level = 122 mm (or 4.80 inch or 0.400 ft)

Then the % of water becomes (rounded off to 0.1%):

$$\% \text{ of water} = \frac{122 \text{ mm} - 25 \text{ mm}}{485 \text{ mm}} \times 100\% = 20\ \% \qquad (24a)$$

or

$$\% \text{ of water} = \frac{4.80'' - 0.98''}{19.09''} \times 100\% = 20\ \% \qquad (24b)$$

or

$$\% \text{ of water} = \frac{0.400' - 0.082'}{1.591'} \times 100\% = 20\ \% \qquad (24c)$$

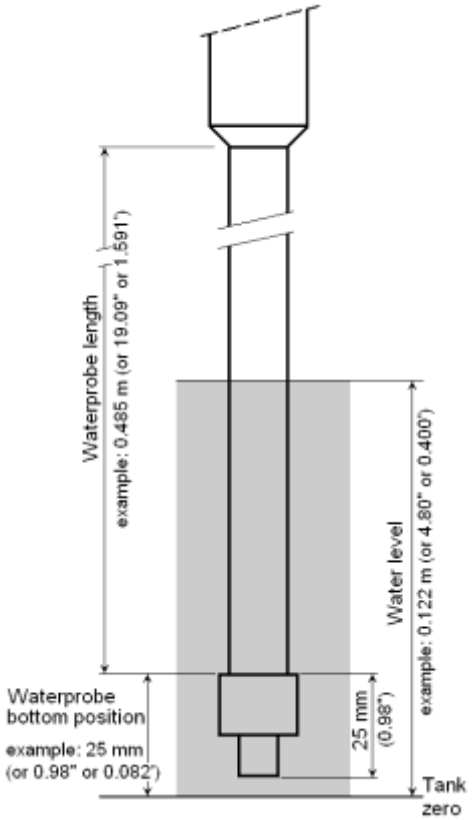

Figure 27 Water probe calibration

The [Minimum water capacity] can be found as follows:

$$C_{min} = C_{max} - \frac{C_{max} - C_{meas.}}{100\% - \%\text{ of water}} \times 100\% \ [pF] \qquad (25)$$

Where:
C_{min} = [Minimum water capacity]
C_{max} = [Maximum water capacity]
C_{meas} = [Measured water capacitance]

If we assume the following numbers as an example:
[Measured water capacitance] = 185.224 pF
[Maximum water capacity] = 430.4 pF (obtained from "Checklist 765/766/768 Final Assembly")
Then the [Minimum water capacity] becomes:

$$\text{Minimum water capacity} = 430.4 - \frac{430.4 - 185.224}{100 - 20} \times 100 = 123.930 \text{ pF} \qquad (25a)$$

Situation 3 (Probe partly covered by product and for the remaining part covered by air)

Refer to the figure 27, but read for the water level: ***product level*** and read for the product: ***air***. The values from the "Checklist 765/766/768 Final Assembly" for minimum and maximum capacitance must be entered in the entities: [Minimum water capacity] and [Maximum water capacity].

- Measure the product level and calculate the immersed part;
- Read the measured capacitance from entity: [Measured water capacitance];
- Calculate new value for [Minimum water capacity] as follows:

$$C_{min(new)} = C_{min} + \frac{\text{Waterprobe length}}{\text{immersed part}} \times (C_{meas.} - C_{min}) \text{ [pF]} \qquad (26)$$

Where:
$C_{min\ (new)}$ = new calculated value for [Minimum water capacity]
C_{min} = [Minimum water capacity] (obtained from "Checklist 765/766/768 Final Assembly")
$C_{meas.}$ = [Measured water capacitance] (obtained from "Checklist 765/766/768 Final Assembly")

For example:
[Minimum water capacity] = 120.0 pF (obtained from "Checklist 765/766/768 Final Assembly")
[Maximum water capacity] = 430.4 pF (obtained from "Checklist 765/766/768 Final Assembly")
[Measured water capacitance] = 120.786 pF
[Waterprobe bottom position] = 25 mm (or 0.98 inch or 0.082 ft)
[Waterprobe length] = 485 mm (or 19.09 inch or 1.591 ft)

1) Product level (measured by manual dip) = 122 mm (or 4.80 inch or 0.400 ft)
   Immersed part becomes:
   122 – 25 = 97 mm (or 4.80 – 0.90 = 3.82 inch or 0.400 – 0.082 = 0.318 ft) (27)

2) [Measured water capacitance] = 120.786 pF

3) Calculate new value for [Minimum water capacity]:

$$\text{Minimum water capacity}_{(new)} = 120.0 + \frac{485\ \text{mm}}{97\ \text{mm}} \text{ x } (120.786 - 120.0) = 123.930\ \text{pF} \quad (26a)$$

or

$$\text{Minimum water capacity}_{(new)} = 120.0 + \frac{19.09''}{3.82''} \text{ x } (120.786 - 120.0) = 123.930\ \text{pF} \quad (26b)$$

or

$$\text{Minimum water capacity}_{(new)} = 120.0 + \frac{1.591'}{0.318'} \text{ x } (120.786 - 120.0) = 123.930\ \text{pF} \quad (26c)$$

The entities [Minimum water capacity], [Maximum water capacity] and [Measured water capacitance] are located on Engauge tab sheet: **Water level.**

- [Minimum water capacity] is the capacity when the probe is not submerged in water (in pF). Value obtained from “Checklist 765/766/768 Final Assembly”, or from above described measurements and calculations. The value range is: <0.0 .. +x.x> (floating point format). Default value is <20000>.
- [Maximum water capacity] is the capacity when the probe is fully submerged in water (in pF). Value obtained from “Checklist 765/766/768 Final Assembly”. The value range is: <0.0 .. +x.x> (floating point format). Default value is <20000>.
- [Measured water capacitance] indicates the measured capacitance of the water probe (in pF). The value must be in range between [Minimum water capacity] and [Maximum water capacity]. Default value is <0>

ADDITIONAL SETTINGS for 365 temperature and water probe

This section describes the necessary settings when two similar FlexConn boards are installed in the SmartRadar FlexLine. For instance to interface the 365 MPT temperature and water probe with the CEPS Interface.
In this case, one FII-VT (board 1) is used to process data from the VITO Interface board for the integrated water probe and one FII-VT (board 2) is used to process data from the VITO MRT Interface for average temperature from the MPT probe (refer to figure 28).

Board instance number

To distinguish the FII-VT boards, each FII-VT board has a unique Board instance number (range: 0 – 9). When installed from the factory, the Board instance numbers are already set different (to 0 and 1).
If a second board is added in the field, the best way to act is as follows:

- Set the Board instance of the installed FII-VT board to: **1**;
- Install the second FII-VT board (default Board instance number is: 0).

The entity [Board instance] is located on Engauge tab sheet: **Generic**.
It is a value ranging < 0 .. 9>;
default value is : <0>

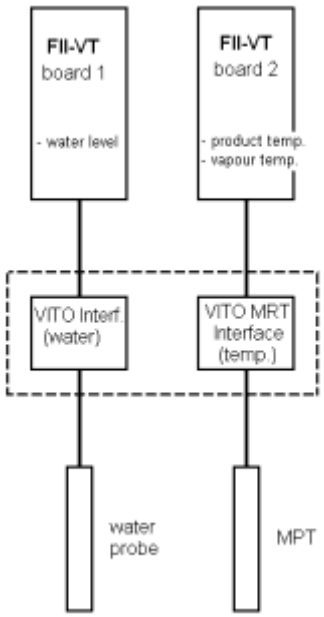

Figure 28 Two FII-VT boards

HART detected device

To know which FII-VT board measures the water level and which FII-VT board measures the temperature, check the entity [HART detected device] on the Engauge tab sheet: **Miscellaneous** of each FII-VT board.

- FII-VT board for water level:
  HART detected devices reads: **765 WATER**
- FII-VT board for temperature:
  HART detected devices reads: **RTD**

Function priority number

As each of the FII-VT boards can measure the same data (product temperature, vapour temperature and water level), the temperature priority function must be set lower on the FII-VT board which is used to measure the water level and the water level priority function must be set lower on the FII-VT board which is used to measure the temperature.

Enter the Function priority entities according the table below (table 17):

Table 17 Function priority

Engauge Tab sheet	Function priority for FII-VT board measuring water	Function priority for FII-VT board measuring temp.
Product temperature	**126**	127
Vapour temperature	**126**	127
Water level	127	**126**

The entity [Function priority] is located on the Engauge tab sheets: **Product temperature**, **Vapour temperature** and **Water level**.
It is a value ranging < 0 .. 255>; default value is: <127>.
To set the function priority lower, any number less than 127 will do.

This ends the additional settings for the 365 temperature and water probe. Continue the other(normal) commissioning settings for temperature and water measurement according the following section in the Service manual SmartRadar FlexLine:

- Product temperature: section 6.10.3.2.1
- Vapour temperature: section 6.10.3.2.2
- Water level: section 6.10.3.1.3

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